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# 3D Printed 3D Printer

A sustainable approach to making 3D printers

THESIS

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## Table of notations

# 1 Introduction

The emergence of additive manufacturing technologies has largely affected the manufacturing industry by enabling rapid production and prototyping services, customizations, and catering to the demand-based production manufacturing areas. Traditionally, FDM 3D printers are manufactured using machine tools and prefabricated components. This can be reduced or eliminated by a process referred to as self-replication. This will give us the ability to create functional 3D printed 3D printers in short, self-replicating machines. This will provide significant advancement towards sustainability, cost reduction, maintenance, and accessibility.

The current 3D printing market uses commercially available components that are pre-produced and outsourced, which makes the machines adjust to them and increases the overall machine cost. This provides challenges for multiple problems for small-scale industries looking to adopt 3D printing technology. This research looks at the possibility of overcoming these limitations by designing and fabricating a 3D printer that is itself primarily 3D printed, reducing the company's dependency while maintaining the functionality of the machine.

The primary goals of this thesis are to determine the viability, design, and performance optimization of a 3D printer that is primarily constructed using additive manufacturing techniques. The future of distributed manufacturing would be significantly impacted if a self-replicating 3D printer were to be successfully implemented. This idea has the potential to lower production costs, democratize technology access, and facilitate localized fabrication, especially in developing or remote areas. Furthermore, improvements in modular design concepts and printable electronics may open the door to fabrication systems that are more flexible, expandable, and self-sufficient.

## 2 Literature Review

### 2.1 Industrial Revolution

The core of the Industrial Revolution shows how they transformed the production of goods and services for societies, which have changed over the years. It shows the significance of speed per unit of capital labor, which means overall efficiency. One of the conceptual frameworks discussed is the pull-push theory: The Industrial Revolution occurs when a disruptive trigger (push factor) aligns with the emerging market needs (pull factor) and breakthrough process technologies. Such alignment not only accelerates productivity but also reconfigures economic structures and social dynamics. Furthermore, some academics propose the concept of an "industrious revolution"—a time in which pre-industrial homes rearranged labor and consumption patterns to create the foundation for later automated industry.[1][2]

#### 2.1.1 Phases of Industrial Revolution

##### 2.1.1.1 *First Industrial Revolution (Late 18th – Early 19th Century)*

Marked by the great invention and widespread application of the steam engine, the 1<sup>st</sup> industrial revolution phase began in Britain. These coal-powered mechanisms powered industries such as textiles, iron, and transportation. The production process was reimagined as the manual processes were replaced by machine-based manufacturing. With so many people moving to cities to work in factories, the shift from an agricultural economy to industrialized manufacturing resulted in notable urbanization. The increase in output and the acceptance of new manufacturing techniques redefined labor roles and drove the emergence of new social classes, changing society.[1][4]



Fig.1 shows the production of clothes in the first industrial revolution. [4]

#### 2.1.1.2 *Second Industrial Revolution (Mid-19th – Early 20th Century)*

During the Second Industrial Revolution, the main breakthroughs were through the invention of electrical, internal combustion, and mass production methods. Factories started incorporating autonomous production lines, more noticeable in industries such as automotive and chemical. The advent of assembly line labor and the availability of a more flexible and efficient energy source—electricity—caused exponential rises in output. This led to larger-scale corporations and more complex supply chains, and an increase in the consumer culture. Special structures improved more as urbanization intensified, and a new industrial category emerged.[1][2][5]



Fig.2 shows the assembly line from the Second Industrial Revolution [5]

### 2.1.1.3 *Third Industrial Revolution (Mid-20th Century – Late 20th Century)*

This industrial revolution is often described as the digital revolution, This phase mainly introduced digital electronics, computers, and automation. During this phase of industrial transformation, there was less focus on a single technology and more on the integration of digital, electronic, and information technologies into the production lines. The introduction and integration of digital technologies into production lead to increased efficiency in areas such as logistics and communications. During this time, a paradigm shift toward a more networked and interconnected world was initiated, laying the groundwork for service-based economies and efficient operations.[1][2][5]

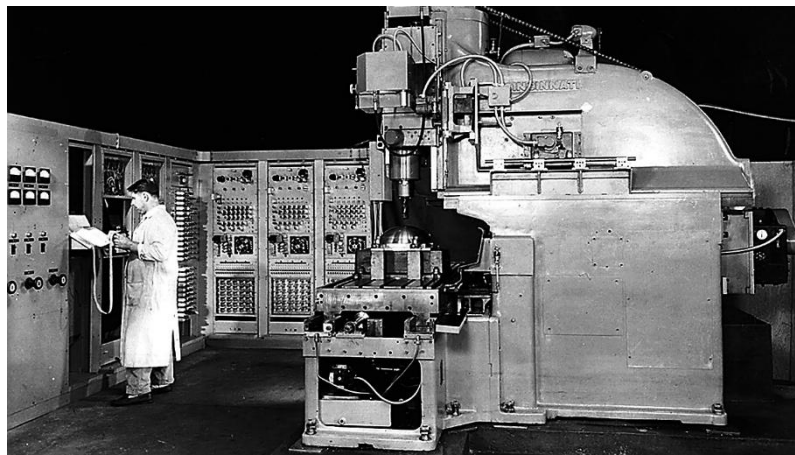


Fig.3 shows the integration of digital computer controls with manufacturing machinery, encapsulating the automation and digitalization that defined the Third Industrial Revolution. [6]

### 2.1.1.4 *Fourth Industrial Revolution (IR 4.0) (Beginning c. 2000 – Present)*

IR 4.0 integrates physical, digital, and biological systems through technologies such as Internet of Things (IoT) (Real-time interconnection of devices, people, and data), Artificial intelligence, and Advanced robotics (Machines that not only perform tasks but also learn and adapt), Autonomous Vehicles, Cloud Computing, and Big Data Analytics (enhancing production and logistics with smarter and data driven processes). Production is being transformed into intelligent, adaptable "factories" during this phase, which is also sparking discussions about economic inequality, cybersecurity, workforce displacement, and ethics. [1][3]



Fig.4 illustrates the transformational evolution of industrial revolutions—from steam-powered mechanization and assembly line production to the digitally integrated, smart manufacturing systems of Industry 4.0. [7]

#### 2.1.1.5 Extended Reflection and Future Prospects

The narratives of the Industrial Revolution and emerging signs of Industry 5.0 show that industrial transformation is still ongoing. Further ongoing development increases the issues with the skilled workforce, ethical considerations, and rights in the data-driven economy, and changing societal structures in a world that is becoming more interconnected as IR 4.0 incorporates the advancements of earlier eras into smooth, intelligent production systems. This continuum of change not only challenges us to embrace technological innovation but also to address its broader socioeconomic impacts. [3][7]



Fig.5 shows the difference between Industry 4.0 and Industry 5.0 [8]

## 2.2 Manufacturing / Industrial Manufacturing

Manufacturing is the process by which raw materials are converted into finished goods through human labor, machining tools, machinery, and physical and chemical processes. This process assists businesses in creating finished goods that are sold at a higher price according to demand. The manufacturing process varies depending on the business's demand and the type of product they want to create. Some of these processes are discrete manufacturing, process manufacturing, and additive manufacturing. Today, manufacturing relies heavily on advanced technologies and strategies, where technologies such as robotic arms and automations are assisted by strategic and planning models such as lean. These help in increasing the overall efficiency and productivity of the system. [9][10][11]

Manufacturing can depend heavily on demand, where large demands for a single kind of product are seen as a single product is produced on a large scale. This production process is called industrial manufacturing. Industrial manufacturing promotes batch production, where large batches are produced, often involving multiple stages of production. It encompasses a wider range of activities beyond just the physical creation of products. Some key aspects are scope, sectors, and technological integrations, as industrial manufacturing processes often integrate a wide range of technologies, including software for supply chain management, energy efficiency equipment, and robots for assembly lines.[9][10][11]

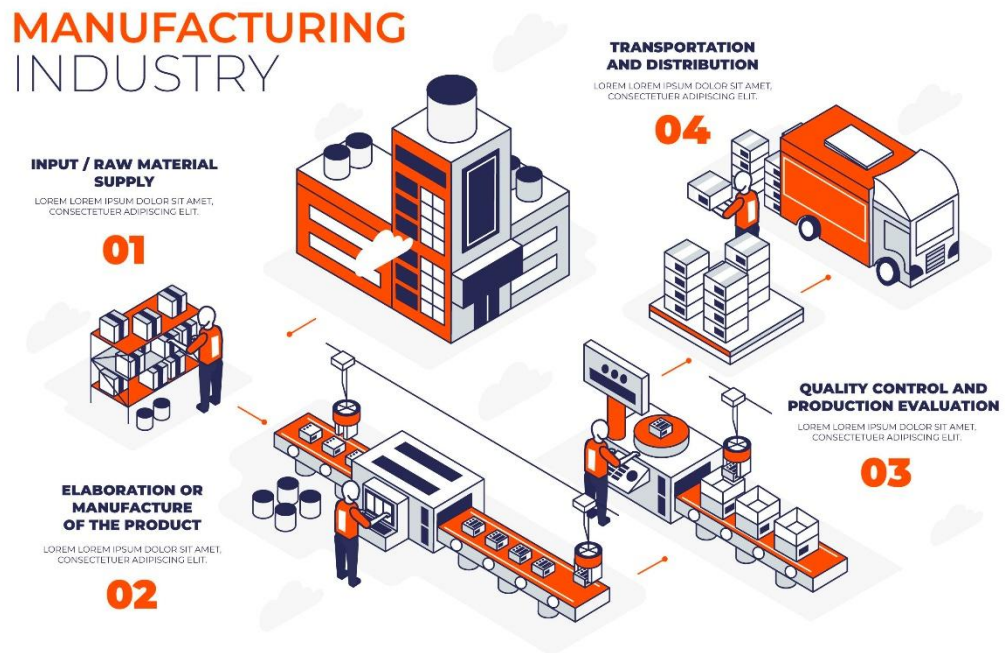


Fig.6 shows an infographic on modern industrial manufacturing [12]

## 2.3 Types of industrial Manufacturing technologies

### 2.3.1 CNC Machining

A CNC (Computer Numerical Control) machine is a modern machining technology that uses high-precision tools that are computer-guided for performing milling, drilling, and cutting tasks with high precision. In this process, the designs are created in a CAM or a CDM software. They are then translated into exact movements for the machine tool, ensuring consistency and repeatability across production runs. The system's integration of adaptive control algorithms and feedback sensors minimizes human error, which allows real-time adjustment to keep tight tolerances. It is mostly used for aerospace, automotive, and medical applications where high precision is required and slight deviations can cause significant issues. [13][14]

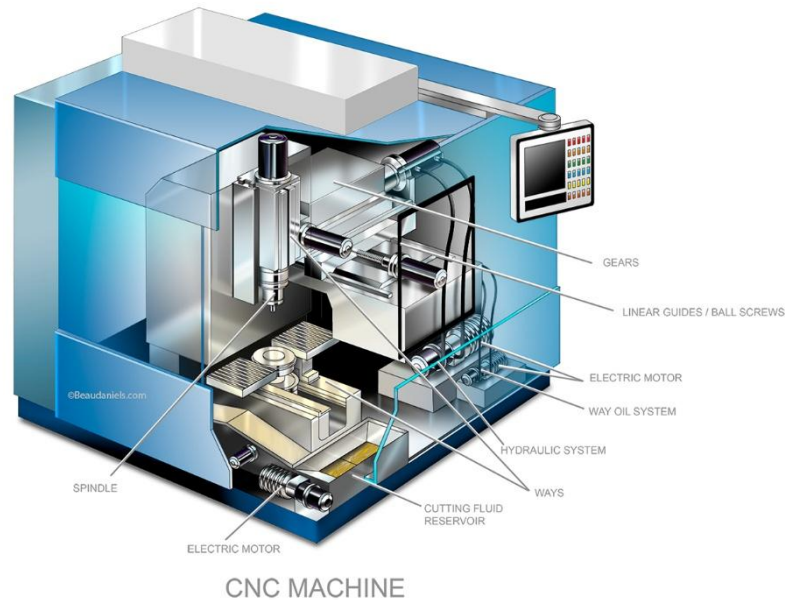


Fig.7 shows a CNC machine. [15]

### 2.3.2 Automation and Robotics in Manufacturing

Automation and robotics have become increasingly important in streamlining modern manufacturing operations. By replacing labor-intensive, repeating tasks, robotic systems increase production speed, accuracy, and safety. These machines are enhanced with advanced sensors and AI algorithms, which allow them to make real-time decisions, monitor performance, and adapt to varying production demands. In all the tasks it performs, from quality checks to welding, it reduces the cycle time and lowers the operational costs. Modern robotics is perfect for high-volume and precise manufacturing environments because of its adaptability, which also makes it possible to quickly reconfigure production lines. [16]



Fig.7 shows a supply chain with multiple robotic welding machines working together [17]

### 2.3.3 IoT & Smart Manufacturing

The Internet of Things (IoT) intersection with manufacturing processes has given rise to smart factories in which every machine, sensor, and control system is interconnected. This integration allows for continuous process monitoring and real-time data collection, by which the production parameters are optimized. This can also facilitate predictive maintenance, which allows the system to diagnose issues by flagging deviations before a failure or downtime can occur. [18]

### 2.3.4 Metal Forming and Casting

Metal Forming and Casting, although traditional, continue to play a vital role in modern production. Metal forming techniques (forging, stamping, and extrusion) depend on plastic deformation of the material to form a shape, whereas casting is the pouring of molten metals into molds to achieve the desired shape. FEA and modern analysis and simulation techniques are employed frequently to optimize process parameters and predict material behavior while increasing the quality control across production runs. The foundational work by Kalpajian and Schmid offers detailed discussions on these classic processes. [19][20]

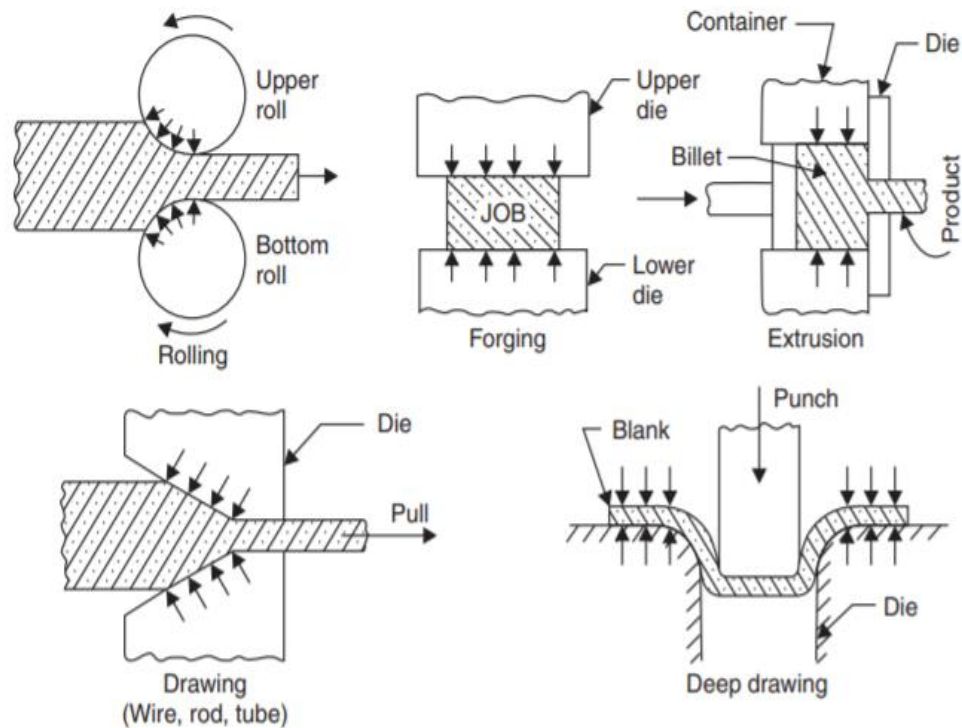


Fig.8 explains the 4 types of technologies: A. Rolling, B. Forging, C. Extrusion, D. Drawing, and E. Deep drawing [21].

### 2.3.5 Digital Twin Technology

Digital Twin Technology revolutionizes manufacturing by allowing the creation of a digital replica of the production system. Engineers can model different operational scenarios, anticipate faults, and maximize performance thanks to these digital surrogates, which are constantly updated with real-time data from IoT sensors. This technology assists in maintenance strategies and minimizes downtime.[22]

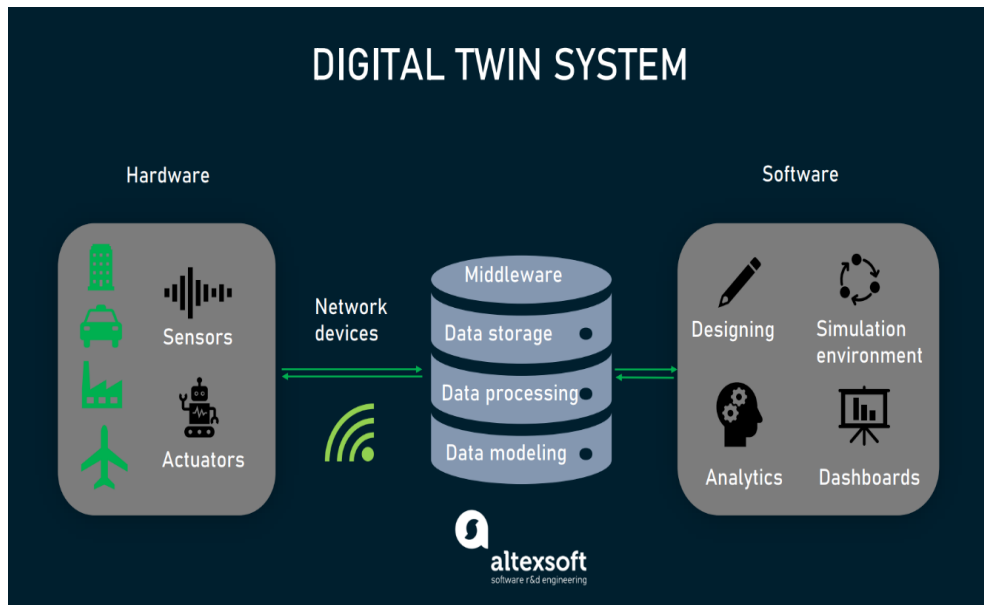


Fig.9 shows how the digital twin system works. [23]

### 2.3.6 Biomanufacturing

Biomanufacturing uses biological processes to produce highly valued products, such as pharmaceuticals, biofuels, and specialty biomaterials. Strict control is necessary for processes including fermentation, cell culture, and biochemical purification in order to preserve product uniformity and regulatory compliance. One of the major challenges that bioprocess engineers constantly face is scaling these processes from lab research to industrial production.[24]

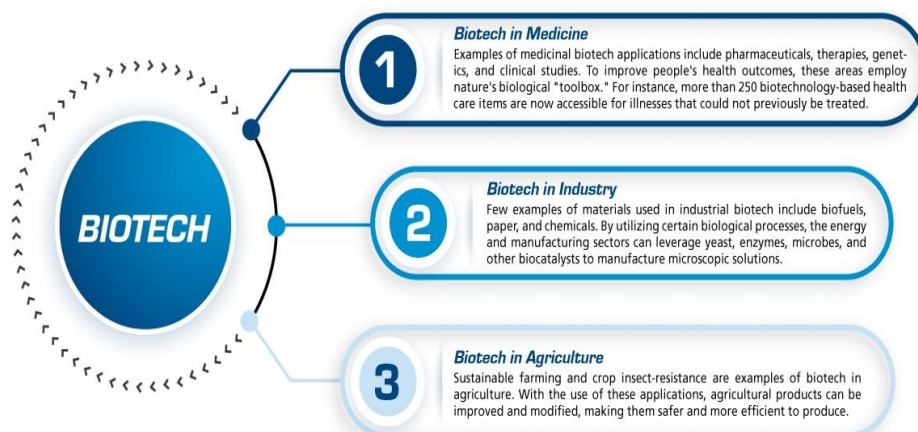


Fig. 10 shows the three primary sectors of Biomanufacturing. [25]

### 2.3.7 Additive Manufacturing Technologies

Additive Manufacturing Technologies, or 3D printing, is a process where a digital model is manufactured by a machine layer by layer by extruding a filament in 2D regular or irregular shapes. This is the reverse of the traditional Subtractive manufacturing technology used by machines like CNC. Unlike subtractive manufacturing technologies, additive manufacturing can make complex geometries by building up the layers. Additive manufacturing technologies allow for a lower material cost and usage, as the part is being built up instead of being cut from the material low or in some cases, no material is being wasted. This technology also allows for rapid prototyping and encourages modern industrial changes where multiple parts can be made at the same time by multiple or even one machines, allowing for customizations and parts that are catered to individual users' requirements. [26][27]

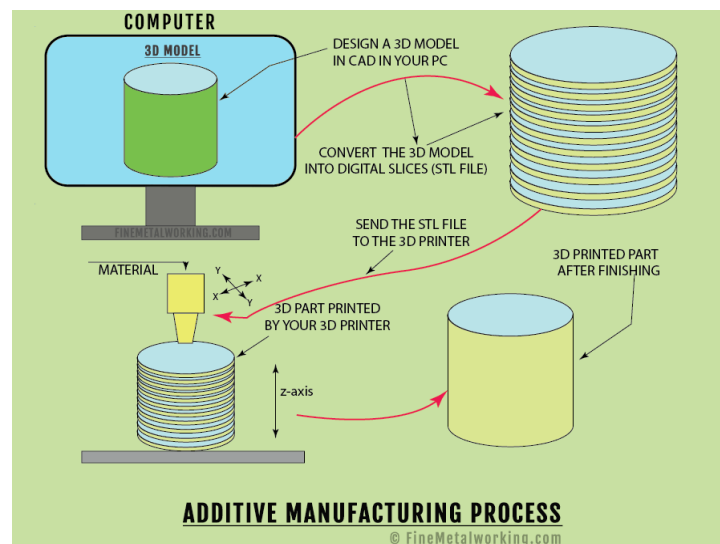


Fig.11 shows how 3D printing technologies work.[27]

### 2.3.8 Types of Additive Manufacturing Technologies

#### 2.3.8.1 Stereolithography (SLA)

One of the additive manufacturing technologies is SLA. It is a method where a stereolithography apparatus is used to turn liquid plastic into solid finished products. The stereolithography machine has 4 main parts: a tank for liquid storage, a perforated platform that is to be lowered into the tank, an ultraviolet light, and a

main control unit, which is usually a computer used to control the laser and the platform. [28][29]

The SLA printing process produces parts that are high-level/quality products and have a smooth surface finish. This can be useful for checking fits and tight tolerances. Thermoset resins are used in the SLA process, of which the material properties may vary depending on the material configuration. [28][29][30]

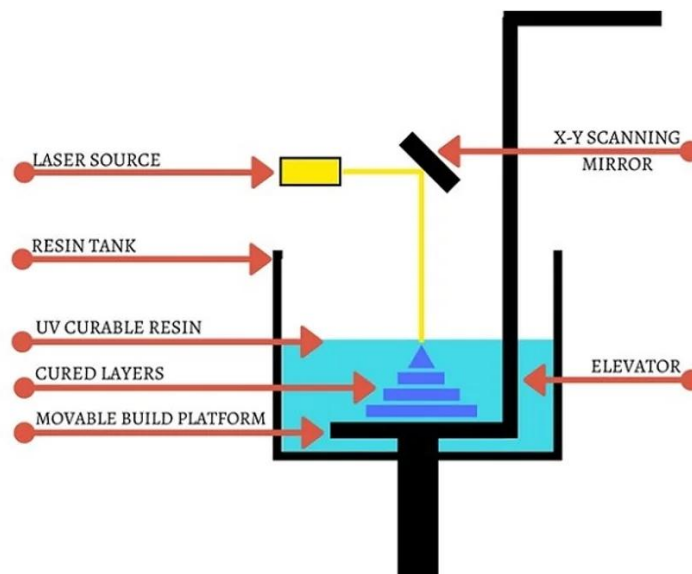


Fig.12 shows components of an SLA machine. [31]

### 2.3.8.2 *Selective Laser Sintering (SLS)*

SLS is an additive manufacturing technology that uses small polymer powder particles for manufacturing. The process uses high-power lasers to bind layers of powder particles together by melting them, which can be stacked up to make a solid part. This technology is suitable for functional testing and snap fits, but it has a rough surface finish. This technology supports non-support printing as the leftover powder can act as a support, and no additional support will be required. It can also print multiple different parts at the same time. [28]

SLS 3D printing technology has proven useful and widely accepted since the start of modern additive manufacturing technologies. This technology supports modern industries as it has a lower cost per part, a higher production speed, and available standard materials, making it suitable for a wide variety of applications such as: Rapid prototyping, bridge, or bespoke manufacturing. DLP technology is also like SLA. [32]

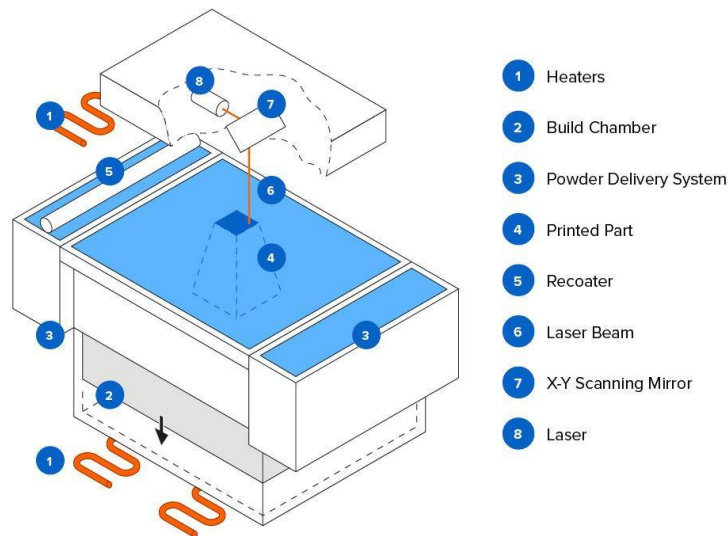


Fig. 13 shows the SLS printer and its major components [32]

### 2.3.8.3 Multijet Fusion (MJF)

Multijet Fusion or Material Jetting is a 3D printing technology that produces a part by solidifying 2D layers of photo-reactive polymers with the help of a UV light. The result of this machining process is a smooth, accurate solid part. [33]

Similar to SLS technology, it can use nylon powder to build up parts. To fuse the agents onto the nylon powder bed, Inkjet arrays are used. The layers are fused by the presence of a hot element. In comparison to SLS, the product of a Multijet manufacturing technology is more mechanically uniform and has better surface polish. It is also faster, which reduces the per-part production cost. [28]

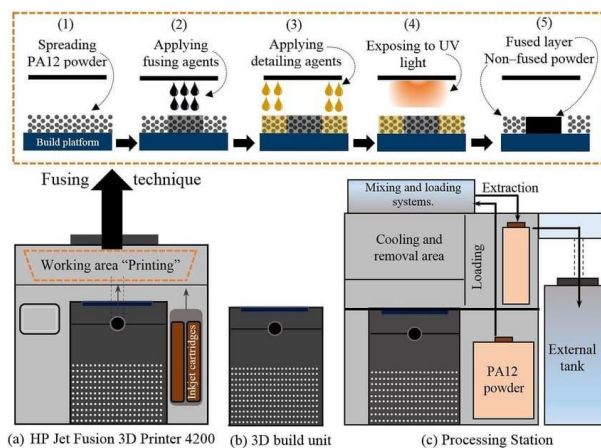


Fig. 14 shows the working process of an MJF machine. [34]

#### 2.3.8.4 PolyJet

PolyJet is one of the oldest additive manufacturing technologies, having been used for over 20 years. Its working principle is like that of an inkjet printer; the only difference lies in its ability to stack up printed layers to form a 3D object. This printer provides the advantage of printing in colour. This technology also allows for multi-material usage. This technology, with an accuracy of 0.014 [mm], allows us to make precise and complex 3D geometries.[33][35][36] These printers are commonly used in offices for dental, orthopedic, media, and aerospace applications. They can also be used for lost-wax casting in jewelry creation [33][36]. Additionally, PolyJet can create moving assemblies, over-molded parts, and different material property components using more than 350,000 digital material options [37].

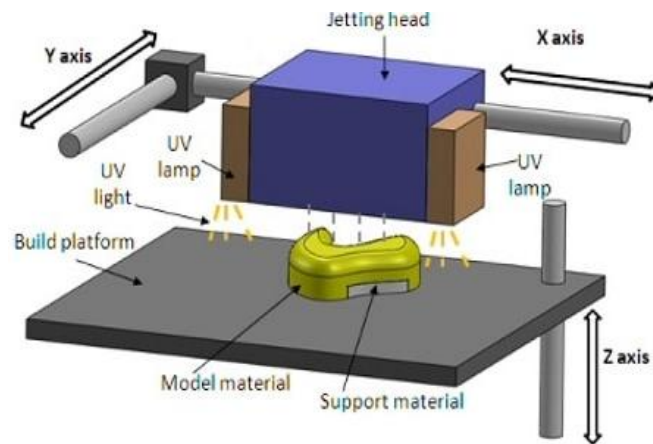


Fig. 15 Schematic presentation of the PolyJet printing process [37]

#### 2.3.8.5 Direct Metal Laser Sintering (DMLS)

DMLS is the most commonly used metal additive manufacturing technology, and many companies use it for metal parts such as jewelry. DMLS provides advanced 3D printing. Commonly, this additive manufacturing method is used to produce lightweight products by using internal patterns with different geometries to reduce the part's overall weight and material usage. As parts produced through this technology have the same density as standard parts, it is suitable for both prototypes and production. Complex metal components with organic geometries can easily be produced through this technology, mostly for medical purposes. [28][38][39]

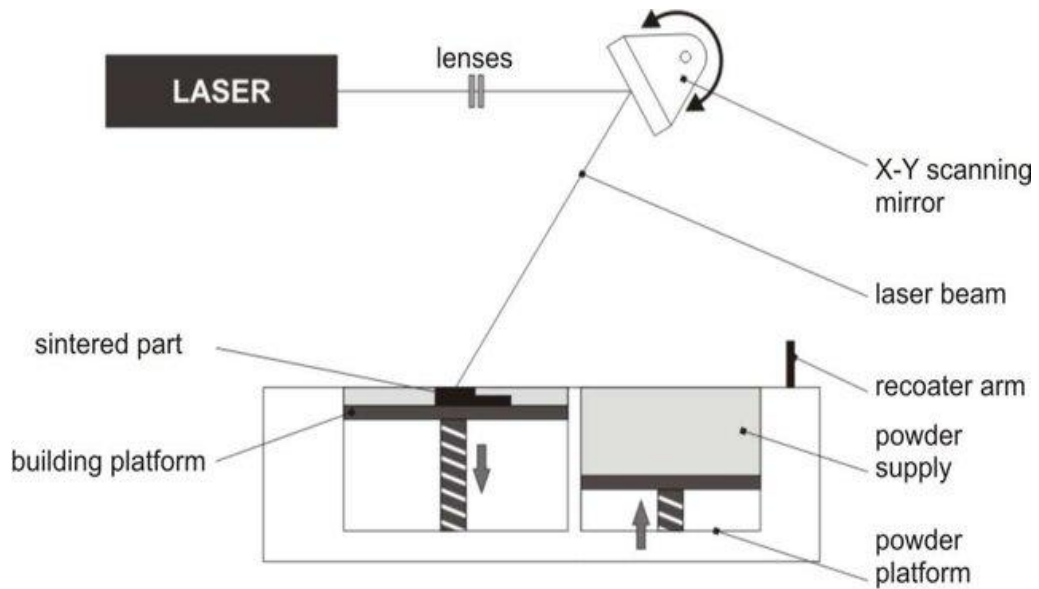


Fig.16 shows DMLS technology and its principles. [39]

#### 2.3.8.6 *Electron Beam Melting (EBM)*

Voxel-based material or highly precise local material modification can be done through the Electron Beam Melting manufacturing process. Features, which get their name from the pixel-based resolution of two-dimensional images. The procedures allow different attributes to be matched to sections of the component. For instance, intentionally vaporizing alloy constituents or meticulously controlling and arranging the intended crystal structure might yield a variety of material properties. [40]

#### 2.3.8.7 *Direct Light Processing (DLP)*

DLP technology uses UV light to expose layers of liquid polymer to harden them and make a solid plastic product. Similar to FDM, this technology has also reduced the overall cost and increased its accessibility. This technology uses digital mirror mechanisms that filter the projector's light. DMD precisely directs the light to the platform. The LCD type usually has a disadvantage due to its use of LCD technology. LCD printers usually have lower accuracy. DLP produces high-quality and surface finish products, although the expensive materials are a disadvantage. [28][41][42]

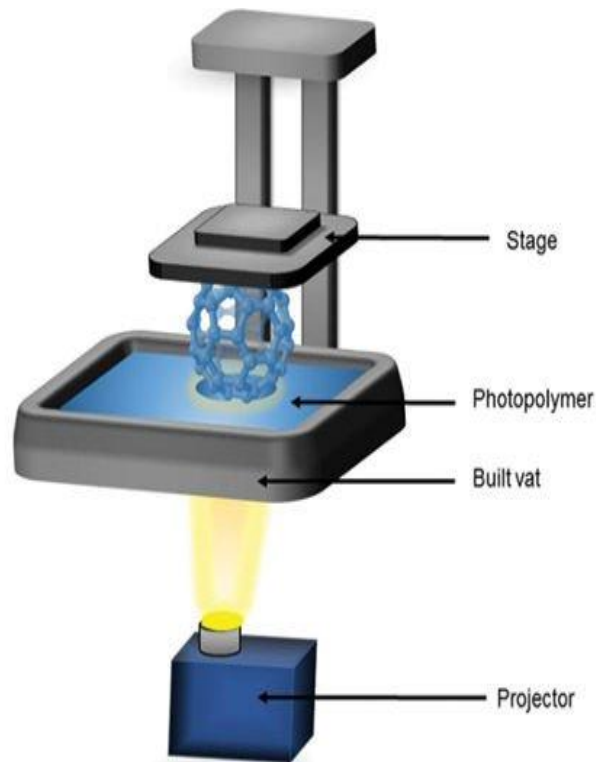


Fig.17 shows the components of DLP printers. [42]

#### 2.3.8.8 Fused Deposition Modeling (FDM)

A FDM additive manufacturing technology works by adding layers of molten plastic on top of each other on a heated build plate, which is usually heated to keep the adhesion of the material on the build plate. The extruder, which is the main unit that houses the extruder motor, a cold end, a hot end, bed leveling sensors, and the belts with the extrusion mechanisms. The extruder moves the material from the extruder motor to the nozzle, which is commonly made from brass in commercial printers. The machine can be easily controlled by an HMI in the machine. The extruder, although many types use gears to force the material and control its flow rate through the extruder mechanism. The bed moves on one axis while the extruder moves on the other two axes. This is only true for Cartesian 3D printers, as mentioned. The 3<sup>rd</sup> type of 3D printers are DELTA 3D printers, which use 3 arms to not only move the extruder in X and Y axes, but also the Z axis helps it to reach

faster speeds. These types of 3D printers usually have circular build plates rather than the rectangular ones that are used by the other types. The most used and the cheapest material for these printers is PLA with a 1.75 [mm] diameter. This technology allows us to use multiple materials, and with time, the materials available are decreasing in price while increasing in variety. High-grade industrial FDM printers can also produce industrial-grade materials such as PEEK. Most modern 3D printers come in an enclosure to maintain the internal temperature of the machine. The enclosures can be heated for high-grade materials and non-heated for maintaining the temperature. Although this has only been seen on limited printers that are commercially available.

FDM additive manufacturing technology allows us to completely control all the variables through which we can control the layer height, speed, and many other variables, allowing for complete control of the mechanisms. FDM 3D printers can have different build volumes, which means that you can find them in different sizes that vary. These additive manufacturing machines range from 200 x 200 x 200, which is commonly used for household uses, to large industrial machines with sizes of up to 1000 x 1000 x 1000. The FDM 3D printers also range in resolution, they can provide which depends on the machine and the material. It can range from 50 to 400 microns. Layer height largely influences the material properties, as larger layers take less time while smaller layers take more time. In short, all these properties affect money, time, and the properties of the produced part. There are two types of FDM 3D printers. Hobbyist and Industrial. While the hobbyist 3D printers are cheap and can produce with a large variety of materials, they have a temperature limit and cannot deal with complex and difficult materials that are prone to warping. Industrial Materials, on the other hand, are superior as they are made with industrial-grade materials and can provide benefits, such as a higher heated chamber, a higher temperature nozzle, and, in general, are made with industrial applications in mind. These can also print high-grade engineering materials and are used for purposes such as rapid prototyping and small-scale batch production. [28][43][44]

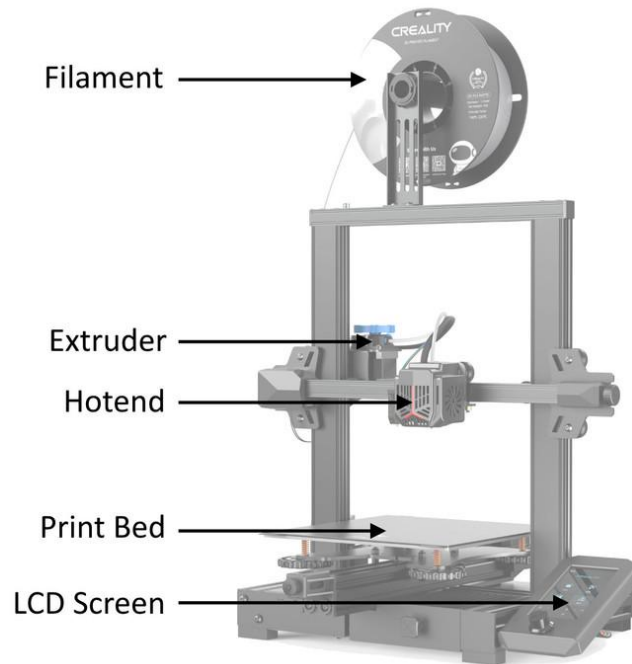


Fig.18 shows a desktop Cartesian 3D printer. [44]

### 2.3.9 Applications for Additive Manufacturing

Additive Manufacturing is commonly used in medicine, and demand has seen considerable growth over recent years. This technology makes prosthetics easily available for more people. Additive manufacturing helped reduce the cost of these kinds of medical tools as it eliminates several processes in the middle. Additive manufacturing allows us to individually customize each prosthetic, making it easier to tailor each one to its user. Additive manufacturing is used in various other medical fields, too; these technologies can be used for unique operations that require printed parts, such as surgery assistance tools. This technology can assist in the field of medicine, where further improvements can help develop heart tissues and other medical tools and organs, too. Additive manufacturing is also very useful in the production of dental parts such as surgical guides, retainers, and more. Using 3D printing technology, a group from Oregon Health & Science University has produced an inexpensive model. The material might lower the ventilator's price to \$10. [45][46][47]

Further development in these technologies has enabled us to make cheap, fast, and automated house constructions. It can assist in areas that have faced natural disasters, enabling us to recover from such problems faster. Although not yet

completely, 3D printing can enhance our efficiency in the automotive industry, allowing us to make complex chassis and parts that cater to individual cars, and making repairs on the cars easier. It can also allow us to make lightweight automotive parts. Bugatti Bolide is an example of a vehicle that uses 3D printed parts that are as fine as 0.1[mm]. [47][48][49]

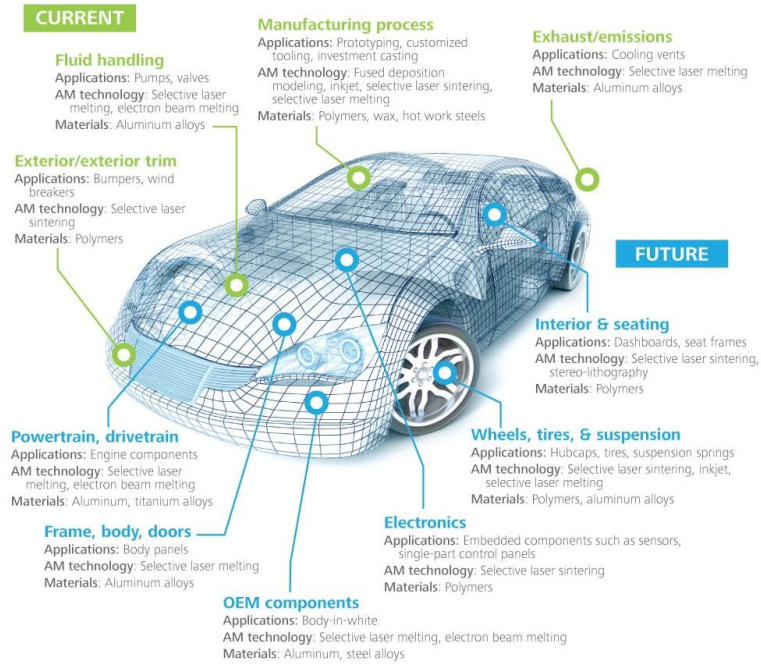


Fig.19 shows the uses of additive manufacturing in automotive manufacturing. [50]

## 3 Additive manufacturing 3D printer parts

### 3.1 Explain why and the expected working principles

After observing all 3D printers, I saw and personally used a Cartesian bed slinger 3D printer. I observed that each technology brought challenges and constraints. I observed that with bed slingers, high-speed forward and backward movement of the bed with the part can cause a lot of problems. These problems vary from a higher belt stress as the machine is constantly moving with increasing stress and load with each layer adding on, and high speeds, making the probability of the print failing higher at high speeds. These constraints allowed me to investigate more technologies, where I saw large (310 x 310 x 310 [mm]), expensive 3D printers using core X-Y technology. These printers had lower constraints and problems that were visible and allowed for parts to be produced with higher accuracy. I had many constraints and areas of concern with the bed slinger 3D printers, where these printers were reducing and, in most cases, solving those problems. After carefully observing Creality K1 Max, I saw a lot of ABS plastic parts that were molded in the 3D printer. Most of the parts could be 3D printed, which would reduce the production cost for the company and make maintenance easier. So, I analyzed the core X-Y working principle.

The core X-Y has a lot of companies that produce these 3D printer kits that other people can 3D print and make a higher-end 3D printer. Instead of those machines, I took inspiration from Bambulab X1C and Creality K1 Max and started designing a printer. The working principle of the printer is that it uses 2 NEMA 17 48[mm] motors in the two corners with a belt and pulley system, allowing the motors to work together to move the extruder in the X and Y axes. The motors have a 32-tooth 5mm hole pulley attached to them, which is connected to a toothless free rotation pulley from one side and a 32-tooth free rotation pulley on the opposite corner. From the free rotation, the toothless pulley, the tensioned belt will move to the extruder. While the toothed free rotation pulley connects to another, making a path to the free rotation pulley on the opposite end of the extruder. The extruder will be custom-built from multiple parts, such as a Creality extruder motor and a Voron Tap bed leveling mechanism, along with the extruder hot end, which will be chosen so that it can maintain temperatures of up to 300 degrees. This mechanism is for both the motors; one belt is on top, while the other is below it. These two belt pulley systems, which you can also see below, are the main motion system for the X and the Y axis of the machine. The toothless free rotation pulleys are on a moving carriage using a smooth rod and a linear bearing. On both sides, the linear motion

carriages are connected to each other with smooth rods. These smooth rods not only connect the two sides but also act as the motion railing for the extruder, allowing it to move left and right. The housing for each thing is expected to be multipurpose, where they will house pulleys, smooth rods, and motors, where required. The Z axis uses 2 motors connected to a threaded rod with a coupling to move the bed up and down. The motors are present in the back, so to provide stability, two arms are added in the front. These arms house linear bearings and are connected to the smooth rods on the base frame. The arms help keep the system stable and give it minimal motion. This entire machine is enclosed in a T-slot aluminum 40 by 40 extruder bar that is connected through a custom 3D printed T joint. The rods will be threaded, and bolts will be used to connect them and every part, as it will make it easier to remove any part when it is required to do so. The entire machine will be designed keeping in mind the Performance, Efficiency, and ease of maintenance (note that all pulleys used will be 6[mm] pulleys).

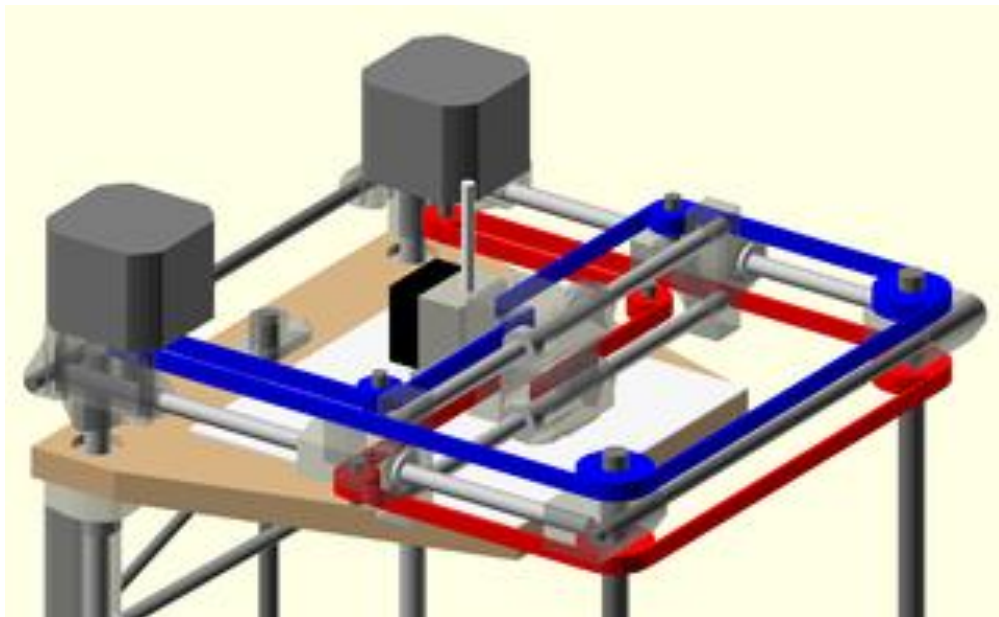


Fig.20 shows the belt connection and working method of a core X-Y Cartesian 3D printer. [51]

## 3.2 Planning the layout and material requirements

### 3.2.1 The Layout of the 3D Printer and motion systems

After observing the core X-Y motion system, I sketched out the system to manually analyze how the parts are going to move, how the motion will be in each pulley, and how a single movement will move us in what direction. I saw general ideas and motion planes and drew a general illustration of how the motion moves the extruder.

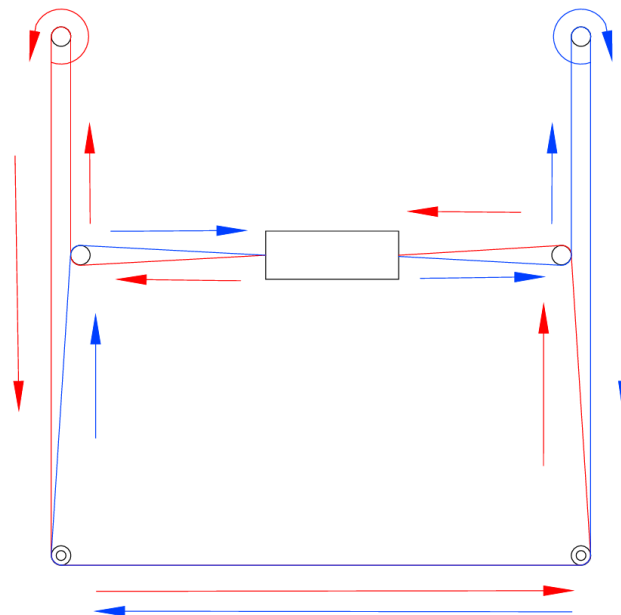


Fig.21 shows the core x-y motion system.

From Fig 21, we can see the motion from 2 motions, the x and the y motion planes. The red colour shows the x motion plane, which has an anti-clockwise motion direction, and we can see the belt moving through the x motion plane pulleys to the central rectangle, which is an extruder. The Y motion plane is shown with the blue colour and has a clockwise motion direction from the motor. Both the motors provide independent motions, and the X-Y plane, as can be illustrated, can be thought of as different from the vertical and horizontal X-Y plane. Further to prove the thought of the x-y plane at 45 degrees rotation, we can separate the motion planes and analyze the motion of the X and the Y axis individually.

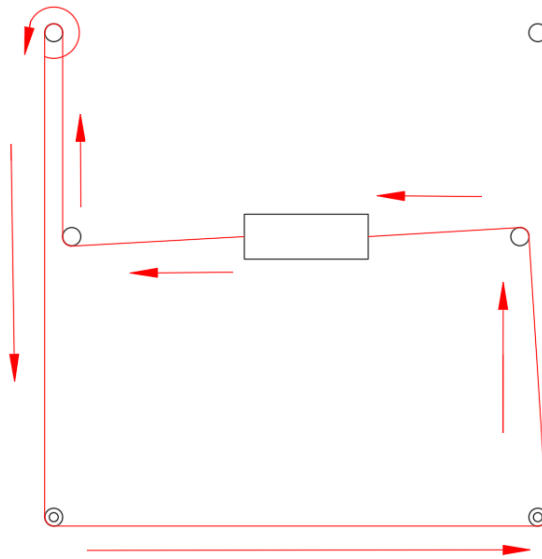


Fig 22. Shows the X axis individually.

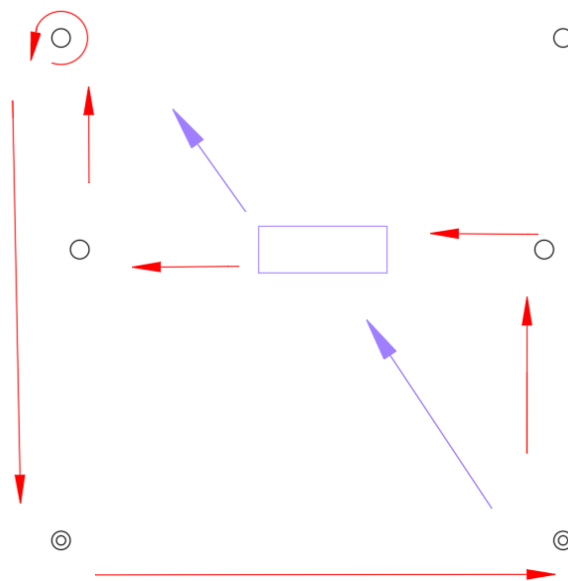


Fig 23. Shows the X-axis motion with the extruder motion direction.

We can analyze the motion and see the X-axis motion from the top. We can see that the motor gives an anticlockwise direction. We will divide the belt into sections and analyse motion in each direction/ section. Firstly, we can analyze from Figure 22 that the overall motion of the belt is towards the motor. We can check this as the

forces pulling the extruder are two: the force moving away from the motor and the force from the pulley to the motor. Using this information, we can assume that the motion of the X-axis that we were expecting is accurate, and the extruder moves in an X direction that is 45 degrees from the traditional X axis. We can see the extruder motion towards the motor in Figure 23 and can assume that the extruder will be moving away from the motor in a diagonal direction if the motor motion is moving in a clockwise direction. Using images 22 and 23, we can assume that the X-axis is a diagonal motion axis as illustrated in Fig 24.

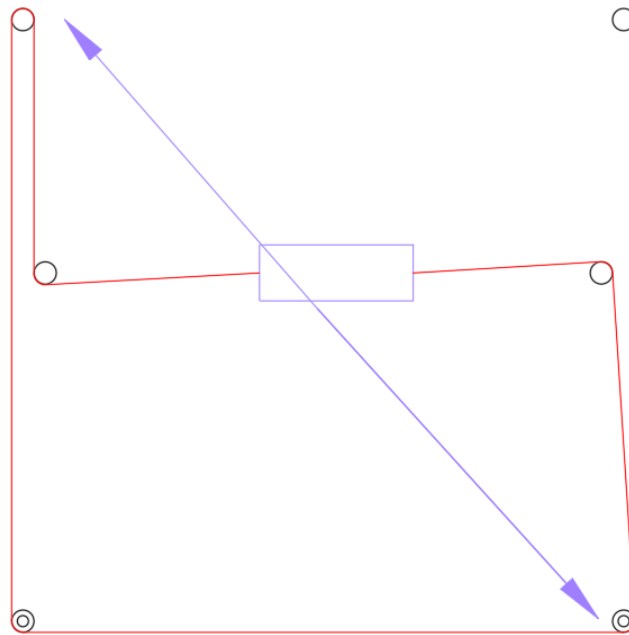


Fig.24 shows the X motion plane in purple.

Similarly, the Y motion plane can be seen in blue; the motor motion is towards the clockwise direction. This was done for 2 purposes: one to analyze the motion plane and secondly to analyze both clockwise and anticlockwise motion directions, which would show us clearly the direction of the plane and the motion of the extruder for both X and Y axes. So, for the Y-axis, we can see the motion of the extruder from the motor motion from the top, where the motor moves in a clockwise direction. We can see the sections of the belt that we used for analysis. We can see that there is a pull force towards the motor and the right of the extruder. We can see this in Figure 25. The belts and the motion direction of the belt against the extruder can be seen. We can further see the direction individually in Fig.26, which shows that the direction of the motion of the extruder marked in purple with the arrow is a diagonal motion towards the extruder.

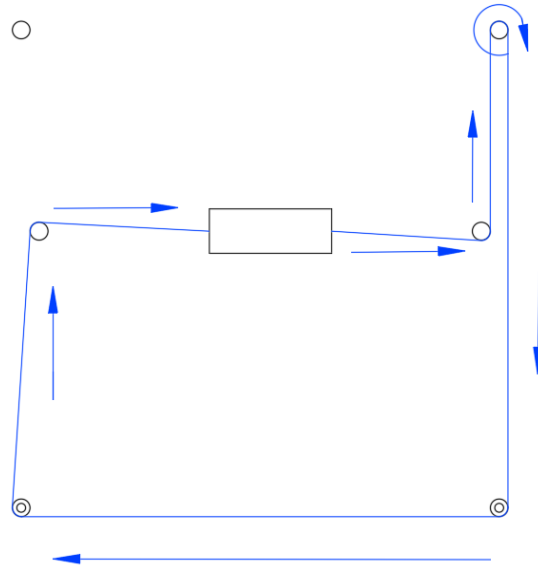


Fig.25 shows the Y axis individually.

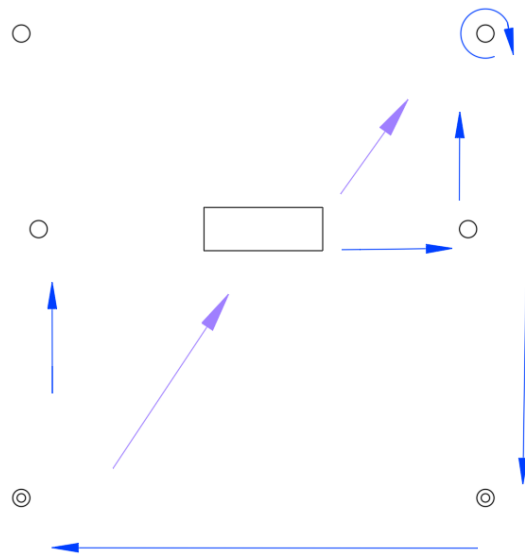


Fig.26 shows the Y-axis motion with the extruder motion direction.

We can analyze the motion independently and assume that an anticlockwise motion direction for the Y-axis, unlike the X-axis, is going to be different. The motion for the Y axis will be towards for clockwise and away motion for anticlockwise motor directions.

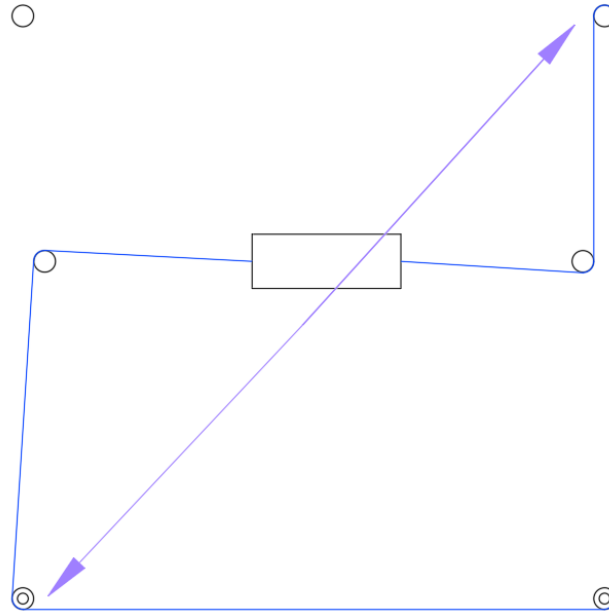


Fig.27 shows the axis of motion for the Y axis.

The Y-axis is similar to the X-axis but mirrored. This shows that the Y axis is also diagonal, proving our point of an unusual or unorthodox axis that is at 45 degree or diagonal. This axis can be seen in Fig.27, where the purple arrow shows the Y-axis. Putting them both together gives us a diagonal X and a diagonal Y axis. Assuming an equal output from motors, we can assume the following: clockwise motion from the X-axis alone moves the extruder diagonally away from the motor, anticlockwise motion brings it toward the motor, and an anticlockwise motion from the Y-axis moves the extruder towards the motor, and a clockwise motion from it will move it towards the motor. Looking at the motors and the motions, a question arises about the motion of the extruder in Fig.21, where X is moving anticlockwise, and Y is moving clockwise. What would be the motion of the extruder in this situation?

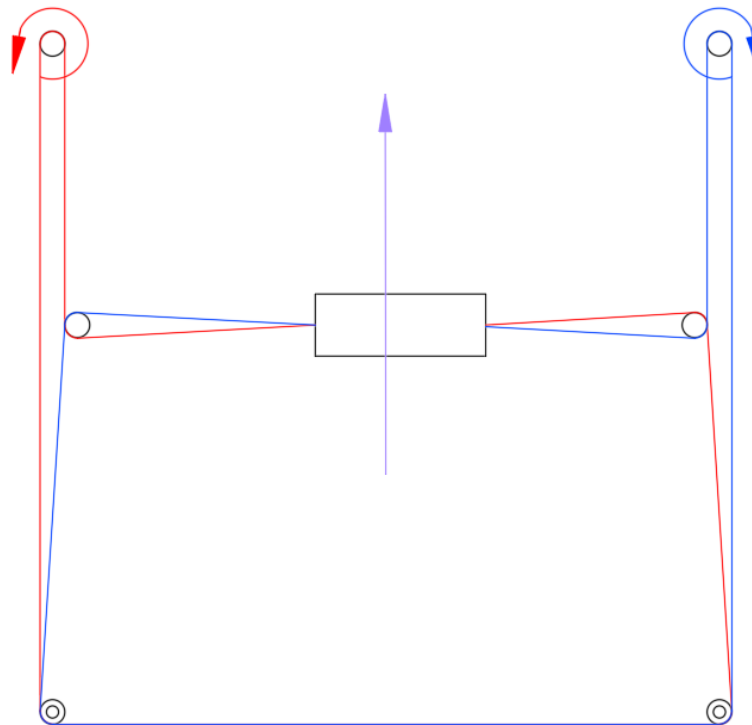


Fig. 28 shows the extruder's motion when x and y move together.

To answer these questions, we can look at Fig.21 and Fig.28, where we can see that the motion of the extruder assuming equal power from both the motors in clockwise and anticlockwise direction will be towards up, the diagonal motions from both cancel out, giving the final motion towards up. So, assuming this, we can make a set of motions as follows:

- If X moves anticlockwise and Y moves clockwise, the motion will be up,
- If X moves Clockwise and Y moves anticlockwise, the motion will be down,
- If X moves clockwise and Y moves clockwise, the motion will be towards the right side,
- If X moves anticlockwise and Y moves anticlockwise, the motion will be towards the left side.

Given this set of motions, we can see that when the motors work in pairs, they simulate a traditional axis. The second thing we can see is if the motors have the same direction, we can assume a traditional X-axis (like if both are clockwise or anticlockwise), while if they have different directions, then we can assume a traditional Y-axis (like if X is clockwise and Y is anticlockwise). This system will be used in the machine, and using this system, we will assume that the axis needs to be up and down to avoid the X and Y axes having any kind of frictional contact.

### 3.2.2 Material Requirements

The starting step of this project was to plan and decide the materials we needed and to source those materials from suppliers. This proved to be difficult as I was in Pakistan at the time, and additive manufacturing technologies (FDM consumer-based) are a relatively new market there. I was able to identify a few suppliers that were using the same parts for different things. Before sourcing, I made a detailed list of all required materials and parts. I had only seen a Creality K1 Max 3D printer at this time. After some research on extruders, I selected a K1 Max hotend with a ceramic heater. This allows it to heat up faster.

After focusing on this, I had an Anycubic Kobra 2 pro extruder already with me with some problems, so after 3D printing the solutions for the internal small blocker, the extruder was working perfectly. For the cold end and the part cooling fan, I already had the Anycubic parts, so I went for those. This saves a lot of budget, and I wanted to make my machine reusable, so I wanted to use some of the parts I already have. I reused the part cooling fan, cold end heat sink, cold end fan, motherboard fan, and the extruder and its casing from the Anycubic Kobra 2 Pro.

For the motors, after some research, I landed on NEMA 17 48mm extruder motors as they are the most common ones used for this type of machine and are easily available, and support sensorless homing. For the motors, I was not able to find many pulleys, so we landed on a 32-tooth pulley, a GT2 28-tooth pulley with bearing, and toothless pulleys with bearing. All the pulleys were GT2 pulleys. The belt selected was a low-flexibility reinforced GT2 pulley belt, 6mm. The 10mm smooth chrome rods were selected for motion systems. Linear bearings with a 29mm length were selected for the moving motion, as shown in Figure 30. The bed was selected with a size of 310x310 mm for any size increases and all. Moving the bed up, I selected 3 threaded lead screws 8mm with 1mm pitch. A creality coupling was used for connecting it with the motor.

A BTT Octopus motherboard powered with an LRS 350-24 power supply was selected with TM2209 stepper drivers, as this combo showed the highest efficiency to price and was able to power up to 8 motors. A traditional on-off switch button and a 3-pin connector were selected to power the power supply. To make the frame of the system, I selected 40X40 T slot aluminum extruder bars for their modularity, stiffness, and strength-to-weight ratio, they can be seen in Figure 29. I



Fig.29 shows the 40x40 aluminum extrusions.

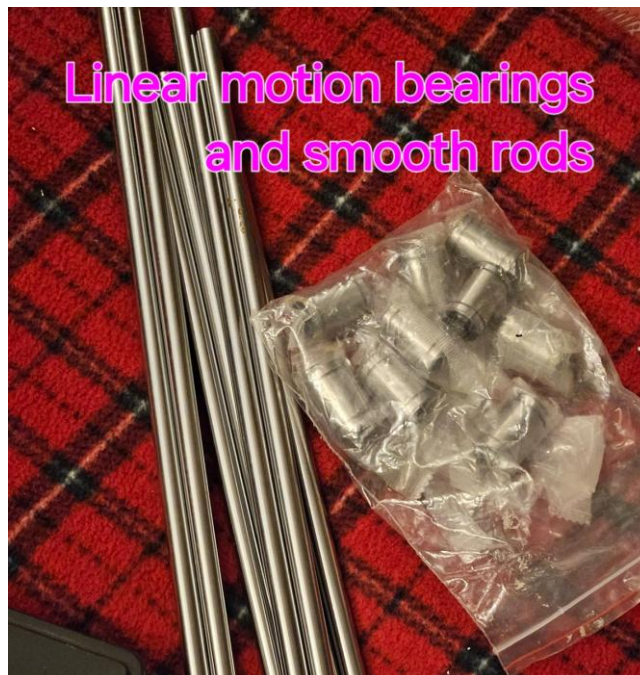


Fig.30 shows the smooth chrome-plated rods and linear bearings.

### 3.3 Material Preparation

Before starting the making or working on the project, I had to prepare the aluminum extrusion bars and the smooth rods, cut them, and prepare the materials for design and my decisions and my making. The aluminum extrusion bars, when they came from the supplier as seen in figure 29, were cut according to the desired length, but due to an error in cutting, they had sides that were not straight, with an error/angle of around 5 degrees. The aluminum extrusions also had another problem: the central holes were not standardized with ISO metric; they were ANSI Inch. I had to start with the aluminum extrusions.

I found a local CNC shop in Pakistan and used their machine to change the hole diameter to 8 [mm], after which I had holes with 20mm depth, and transported all items I bought there to Hungary. After bringing the rods to Hungary, the first thing that was done was threading the rods. Using a thread-making oil as a lubricant and a threading tool with the supervision of Professor Balogh Gabor, I threaded all the aluminum extrusions. This process can be seen in Figure 31. As aluminum is a soft metal, this was relatively easier.

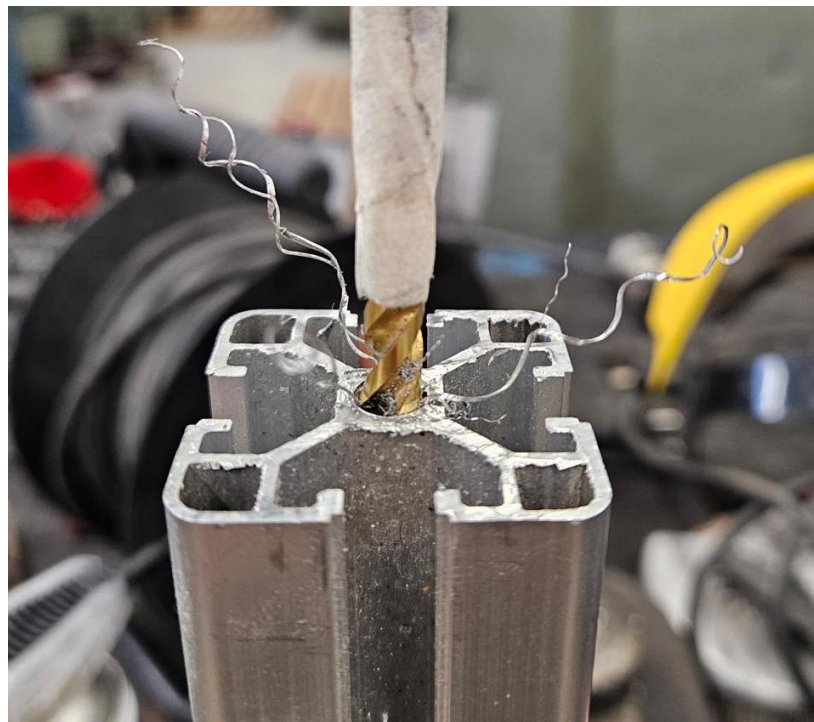


Fig.31 shows the thread-making process.

After this, the problem with the edges and the surface finish of the corners was realized, after which the edges were retrimmed. This did affect the plan we had for the printer, as now we had to make it smaller, but the overall design is focused on modularity, which we will see later. The aluminum extrusion was marked with the accurate cutting length. Extrusion bar was safely set in place, unlocking the latch seen in black in figure 32, after which it was moved closer till it holds the extrusion and doesn't allow any motion. The extrusion bar was also moved forward till the point we marked was in the cutting area or next to the cutting blade. This was to avoid excess motion and allow the extrusion to be cut accurately. After this, the Lid of the machine was closed as shown in Figure 33. After closing the machine lid for safety, the green button was pressed, moving the rotating cutting tool and allowing for the cooling liquid to exit. After this, the handle seen on the right-hand side of the machine was used to move the cutting tool accurately so it could cut the rod (figure 33). The handle was used to move the cutting tool smoothly with a single, slow, and steady motion to avoid error. If there was excess resistance in the cutting motion, it was moved out, and the cutting blade was moved again. We can see the part that was cut in Figure 34, where we can see both the residue of the cut and the main part with an accurate surface finish. After finishing it, the surface finish was checked, and the thread was checked to make sure the cutting process was accurate and that the threads remained intact.

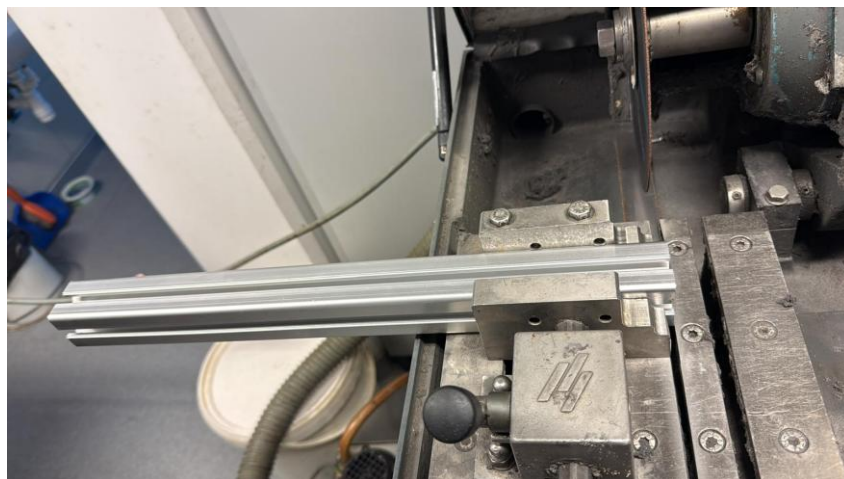


Fig.32 shows the aluminum extrusion being clamped in the machine for cutting.



Fig.33 shows the machine with its lid closed.

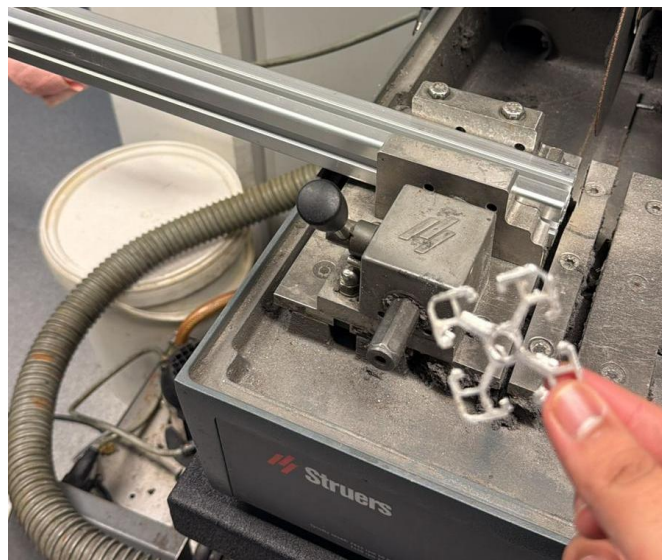


Figure 34 shows the part after the cut and the cut part.

The process that was used to cut the extrusion bars was repeated with the chrome-plated smooth rods, and the threaded rods were cut, similar to the extrusions; they

were marked. After marking them, they were placed inside, where the mark was aligned with the blade, and the cut was performed as we saw with the other in a single motion, giving us the parts in accurate lengths. After preparing these parts, we were able to move forward with the preparation of the 3D models and make decisions on all connections between the parts.

## 3.4 Printer design decisions

### 3.4.1 Manufacturing the outer frame

#### 3.4.1.1 *Designing the idea of a corner joint*

Before making the other parts, I needed to design a way of joining the aluminum extrusions together. There were a few designs I saw personally of people, where they were using sheet metal 90-degree connectors to join the parts through the slots in the extrusion. Considering the Threads I made and the holes in the top, and taking inspiration from the design of a corner joint in figure 35. Taking this design, I designed the part that can be seen in Figure 36. This was a 3-sided connection that allowed us to connect the part at 3 points while maintaining the 90-degree angle for the frame. The first design was such that when I was printing it, just the weight of the X-Y gantry would have broken it. Considering this the design went through several improvements.

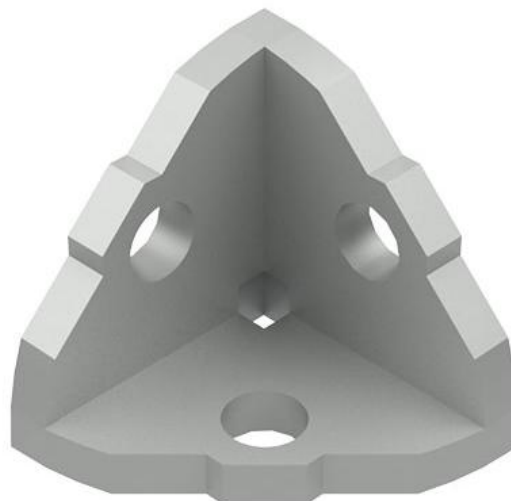


Fig.35 shows a 3-way corner bracket [52]

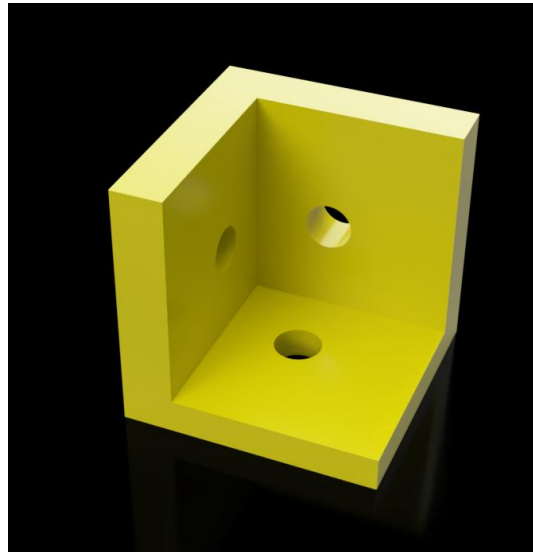


Fig. 36 shows the first design of the corner joint.

#### *3.4.1.2 Designing and troubleshooting the corner-joint*

After noticing that the breaking was mainly in the joint that is shown as a red line in Figure 37, I planned on reinforcing the joint in a way that would reduce the breaking, so that the part wouldn't break.

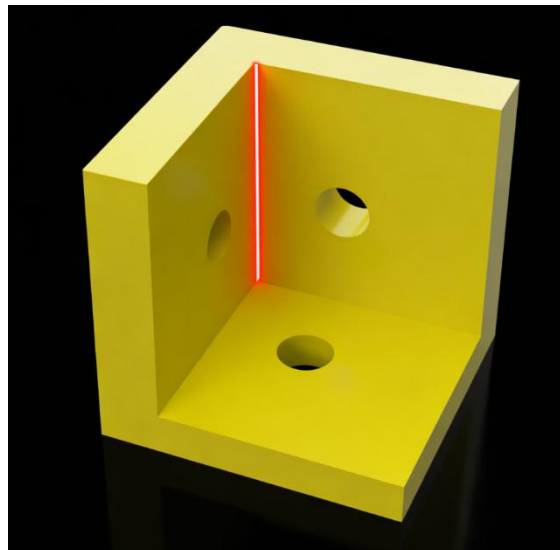


Fig. 37 shows the red line where the part breaks

After these considerations, I planned on making the part in a way that I would reinforce the part and make it completely filled with circular cutouts for the screws and the tools as can be seen in figure 38. This reinforces the part and allows for the

screw to enter but what I was looking at was optimized part that can be used at multiple areas. So, the problem was that the material usage was more than what we could and what I thought it should be.

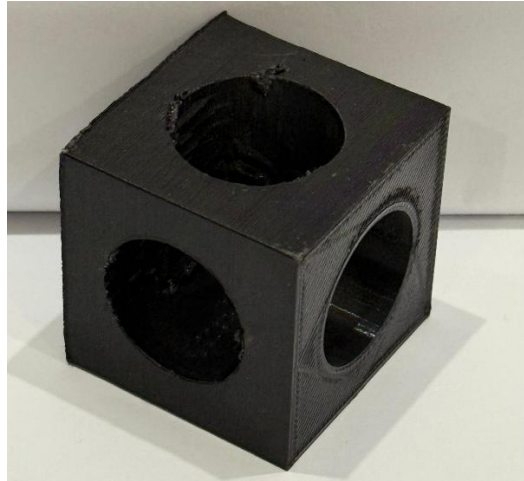


Fig.38 shows the second version of the corner joint.

Considering these problems, I redesigned the part again, and yet again I faced another problem. The redesigned part had supports from top and bottom, and 3 sides, as shown in Figure 39, while the problem I was facing was related to the tolerance of the screws. The screws were close enough that a small slip in my hand would break the support. This breakage can be observed in Figure 40. The screws were continuously getting stuck due to this problem. Although the strength of the part was great, the screw fixing was a big problem.

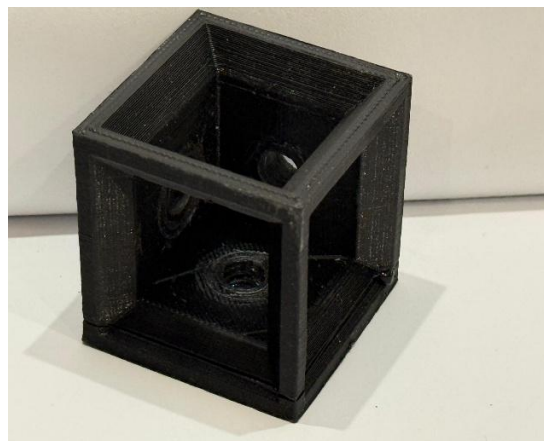


Fig.39 shows the third version of the corner joint

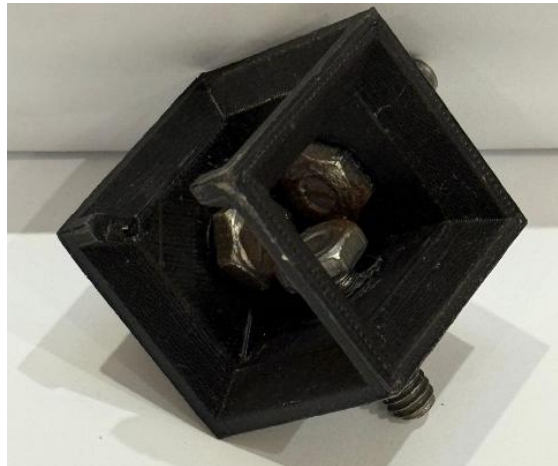


Fig.40 shows the problems in the design

#### *3.4.1.3 Final model of the corner joint*

After understanding the problem and fixing all the problems, the final T joint was made. I created a 3 [mm] deep circle inside the part that allowed the screw to move a bit more towards the inside, giving higher clearance for the tool and solving the part. This part was printed at 30% infill and showed high strength and rigidity of the frame.



Fig.41 shows the final part.

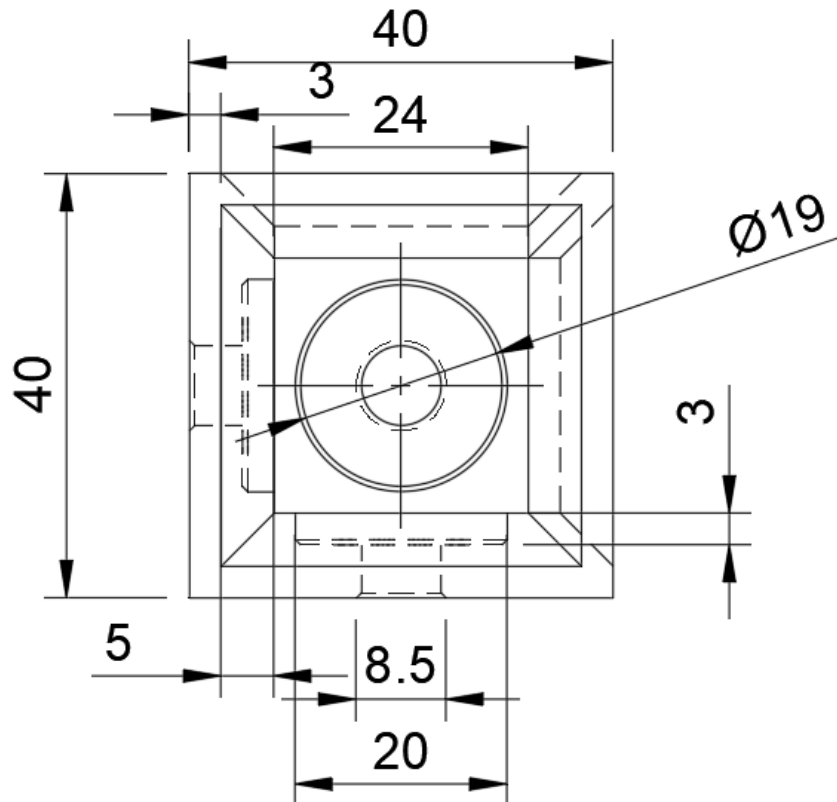


Fig.42 shows the dimensions of the part.

The part was connected to each corner of the 3D printer, where the entire frame was prepared with this. The frame was tested with physical weights, where it showed resistance to a load higher than 80[kgs]. The dimensions of the part can be seen above; the material used for the prototype is PLA, as it is a cheaper filament. The final part will be made from a relatively stronger material, ABS plastic. The infill density was selected as 30% based on my prior test, where 30% showed high stress and strain. The infill was selected as a gyroid due to its ability to maintain both high stress and strain. The part follows the modularity aim I am going for, as it can connect any frame and can act as a corner support. Although side supports might be needed for larger printers, based on the size of the machine. For this machine, these mounts were easily added and can be seen below in Figure 43. This prepares the base frame for the machine.



Fig.43 shows the main frame of the machine.

### 3.4.2 Motor Mount Design

#### 3.4.2.1 *Motor mount X-axis*

The motor mounts were designed with the modularity concept in mind. Initially, the motor mount was going to be a basic rectangular shaped motor mount that is going to hold the motor inside while the motor gets connected to the top, as seen in Figure 44.



Fig.44 shows the first motor mount design.

This was a common design, but when I connected the belt to this, it brushes with the screws, so I used the extrusion bars as a clamp and a screw that tightens onto the internal slot nut holder. This design allowed us to clamp the motor tightly and then use the space efficiently. The motor weight became a problem in this, and I needed to add some bracing on both sides to support the suspended motor holder, and the motor was on the bottom this time. This made the motor mount stronger and suspended the motor, and can be seen in Figure 45.

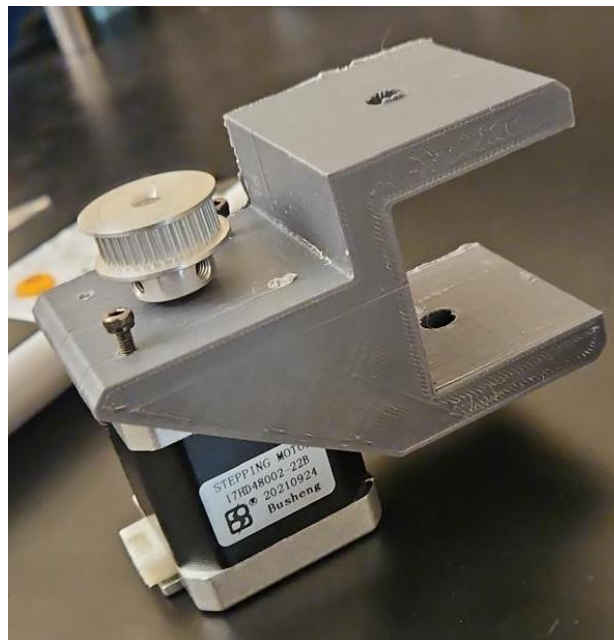


Fig.45 shows the motor mount design 3.

Although this design was supporting the machine and was working perfectly in every way, I wanted to upgrade it. The reason for the upgrade was that the part of the smooth rods needed to fit within it, too. I wanted the part to be multipurpose, where it supports the smooth rods and holds the motor, so I created a circular part on top that allowed me to fit in the smooth rod with a 0.5 [mm] tolerance. The motor mount was up as the upper axis of the belt system was selected as the axis for the X motors and the belt system. As shown in Figure 46, the mount supports the motor while the top part supports the smooth rod. The hole on the side is to keep the rod in place. A semicircular hole in the back makes sure the screw enters with ease and is easy to remove, too. The rear is also open, allowing the smooth rod to pass

through for easier removal and to disassemble and assemble the machine easily. You can see the dimensions of the part in Figure 47.



Fig. 46 shows the X-axis motor mount.

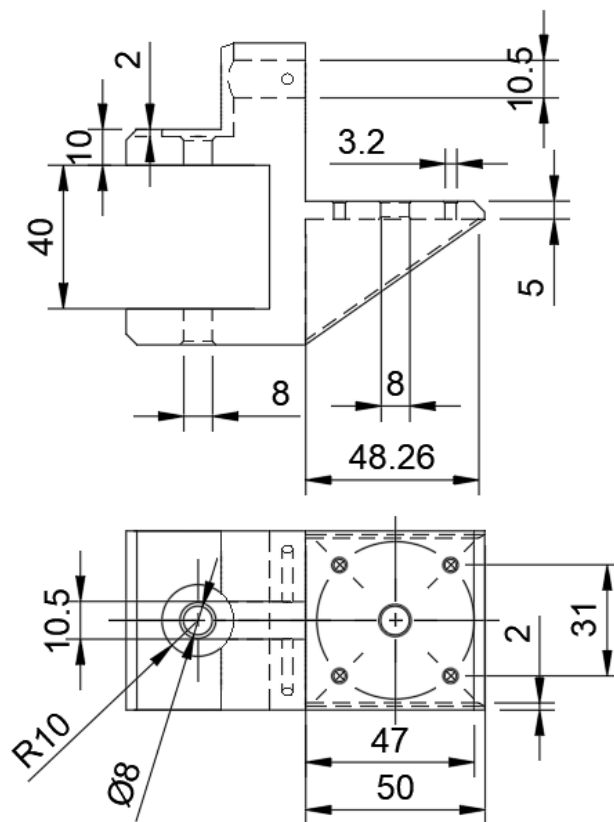


Fig. 47 shows the dimensions of the X-axis motor mount.

### 3.4.2.2 *Motor mount Y-axis*

The Y-axis motor mount, after making the X motor mount, was easier as they follow the same design principle. The X and the Y axes have one major difference, which is the height, due to which the 2[mm] thick support I added for the motor wasn't as suitable, only due to moving the motor mount down for the Y axis. The motor mount can be seen in figure 48, which has moved below, and the supports were added on the top and the bottom. This increases the rigidity and strength of the part. The Dimensions can be seen in Figure 50. The back uses the clamp system to connect to the frame. It is then screwed in from the top and the bottom. Similar to the X axis, the Y axis also fits in and is tightened. The X and Y axes are at different heights. This will allow us to move the x and y axes independently and avoid friction or contact between the axes. You can also see how the motor clamps on in Figure 49.

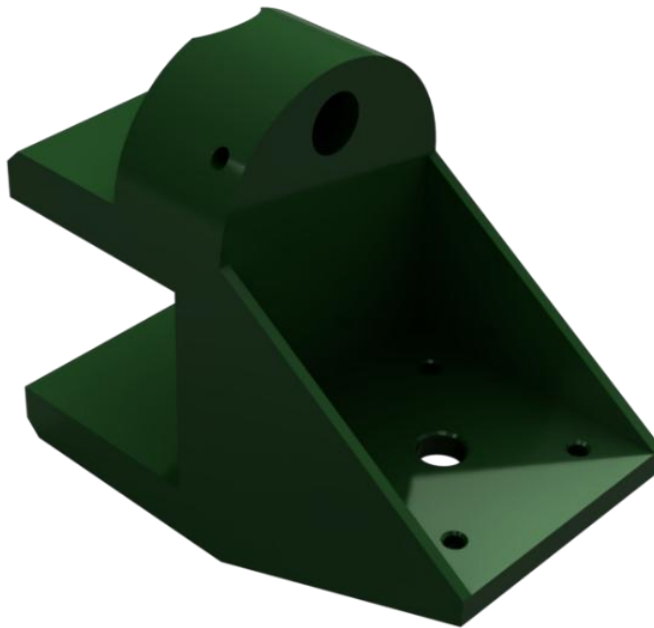


Fig. 48 shows the Y-axis motor mount.



Fig. 49 shows the motor mount fitted into the frame.

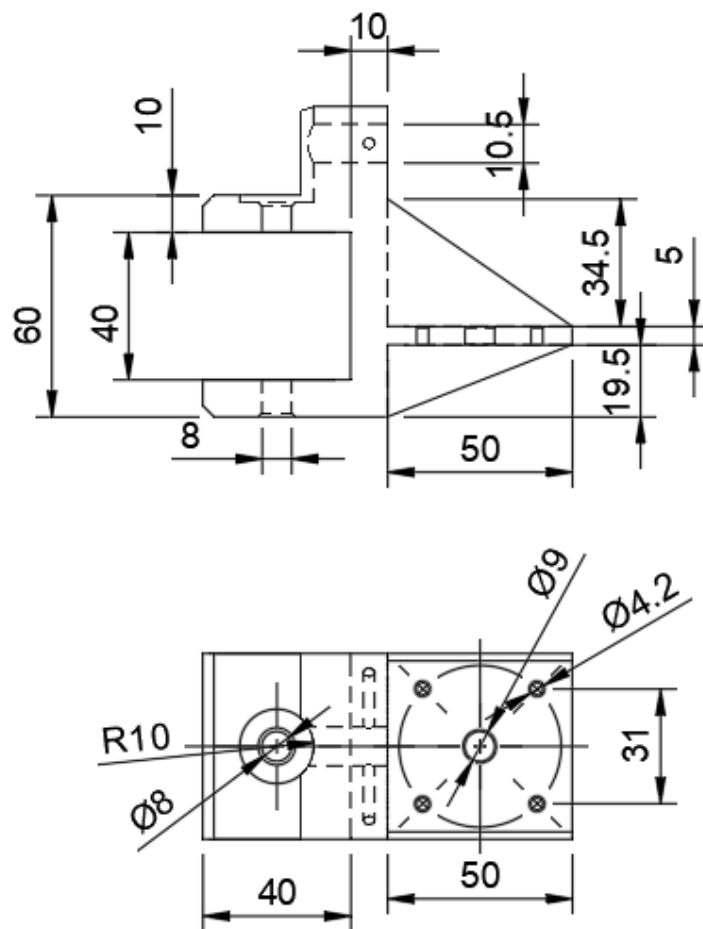


Fig. 50 shows the dimensions of the Y-axis motor.

### 3.4.3 Bearing mount opposite side axis

The opposite axis has the main task of moving the belt from the left side of the X central gantry to the Y central side. To design the central gantry, the first thing was to make a cone-type holder for the bearings. So I designed the part that can be seen in Figure 51, where you can see the holders for the freely moving pulley. This was checked for strength and had a central motion area through which the screw can be tightened.

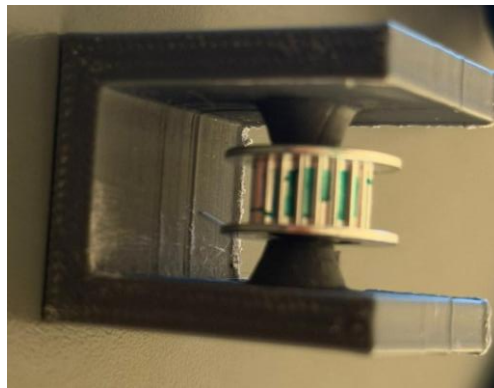


Fig.51 shows the concept of the bearing holder.

Based on this, I checked the difference between the height of the motors for the X and the Y axis so that I can make sure the freely moving toothed pulley is parallel to it with a low tolerance. Based on this, the part was designed. Similar to the motor mount, these free-moving pulleys also have C-shaped mounting holders. This is then screwed inside, and the screw is fixed with the slot nut holder. You can see the part below in Figure 52. The part has two areas, the bottom and the top, directly aligned with the motor mounts for the X and the Y motor mounts. It will be placed opposite to both the X and the Y motor mounts. Similar to the Motor mount, I wanted this to have a double purpose too, so I added the other end of the smooth rod on top of this. It is also a through hole, but to make sure the smooth rod can only exit from the motor's side, the cut and screw were placed in a way that they also act as a stopper for the smooth rod. To make sure the smooth rod hole has enough strength, I added the supporters behind it to make sure the part is rigid enough. A single through screw locks the horizontal translational motion of the bearing, while the conical-shaped holders lock the translational motion, allowing for only the rotational motion of the toothed free rotating pulleys.

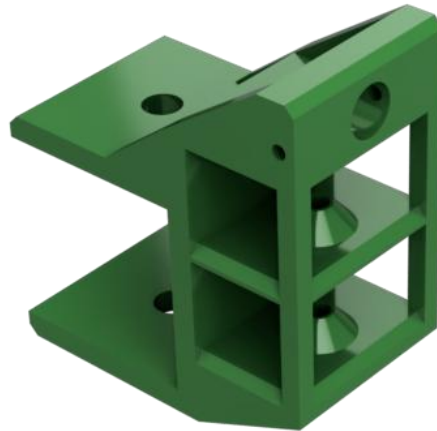


Fig. 52 shows the opposite-axis bearing mount.

This design made it easier to keep the belts separated while following the modularity, giving multipurpose to the part and making sure the belts don't come into contact. You can observe the dimensions of the part in Figures 53 and 54. Figure 55 shows the close connection between the conical holders and the pulleys.

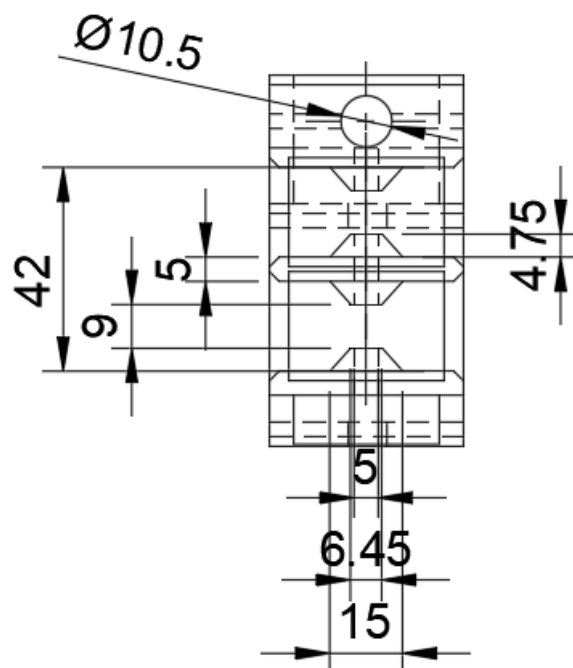


Figure 53 shows the front-view dimensions of the pulley mount.

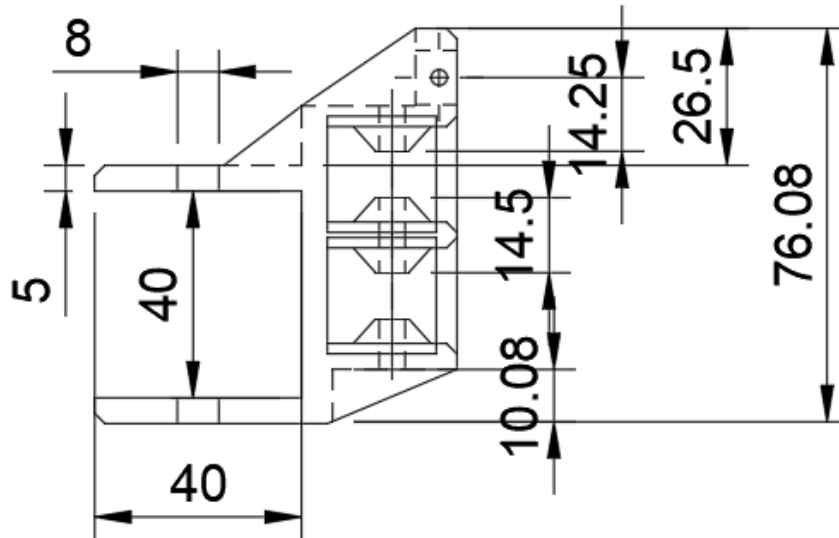


Figure 54 shows the side view of the pulley mount.

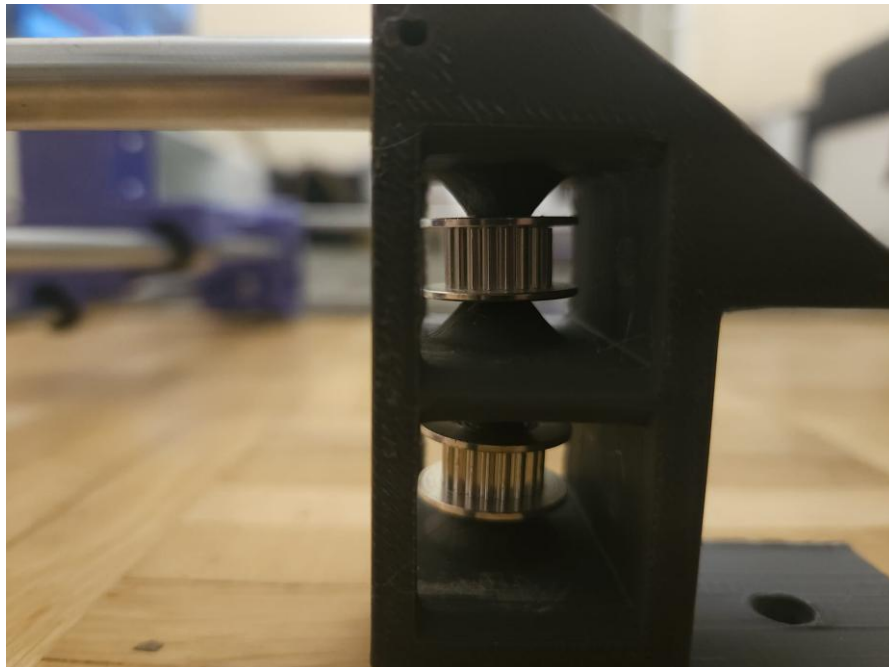


Fig. 55 shows the side view of the pulley holder.

### 3.4.4 Central Axis Mount

The central axis is a linear motion axis that is supported on the smooth rod and is held by the bearing. The central axis was initially designed with a huge and bulky design. The axis was supposed to be light, and weight was supposed to be saved as much as possible. Initially, I used a design similar to the Creality K1 max axis, where the two smooth rods connecting both central axes were placed diagonally, and the extruder was placed in the middle. This can be seen in Figure 56. This was then changed and replaced as it was showing some complications for the design of the extruder mount. This type of fixed mount was also wasting a lot of space. Another issue I was facing with this mount was with the bearing casing, as the bearing casing was not covering, and the nuts weren't fitting properly. This was causing a lot of misalignments, problems with putting the part, and it was making the part heavier while making it weaker in terms of strength.

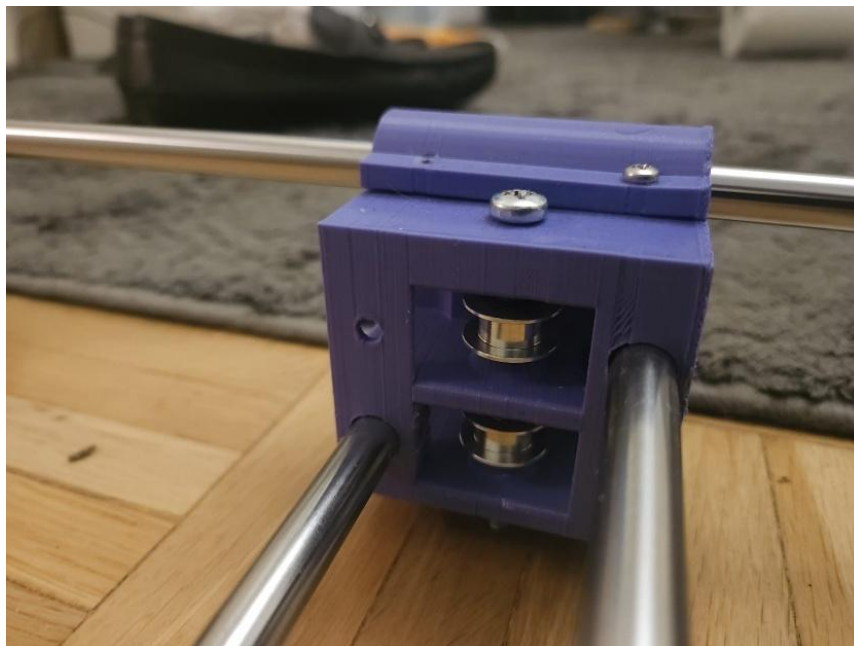


Fig 56 shows the first design of the central axis.

The central axis was fitted and can be seen in Figure 57, where you can see it fit into the frame with a dummy extruder to see the overall design layout. After this, it was checked that the side gantries weren't good enough, and the bearing holder at the top was impractical and had a high chance of breaking under low loads. This also prevents us from using it for larger 3D printers. So I redesigned it into a split-

open gantry, which is designed in two pieces, and can hold the beading assembly and the linear bearing inside, enclosed.

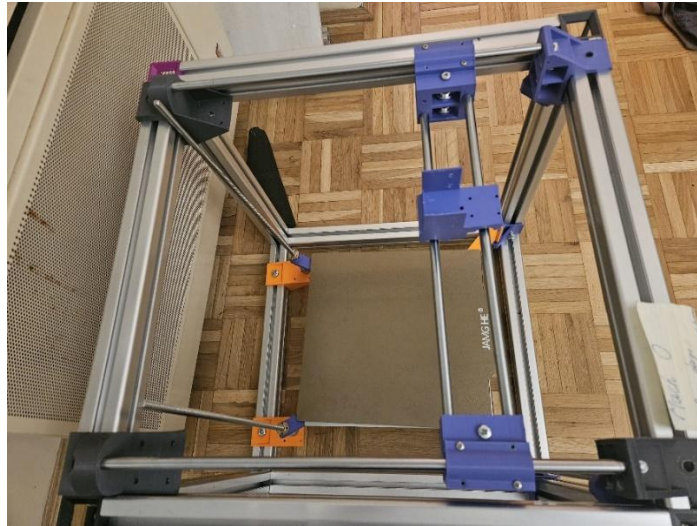


Fig. 57 shows the mounts and original gantry design.

The new design that I made was smaller, reduced weight by more than 10%, and increased the used area by a lot, too, as we moved the smooth rods into a simple, straight linear holder type similar to an Anycubic Kobra S1.

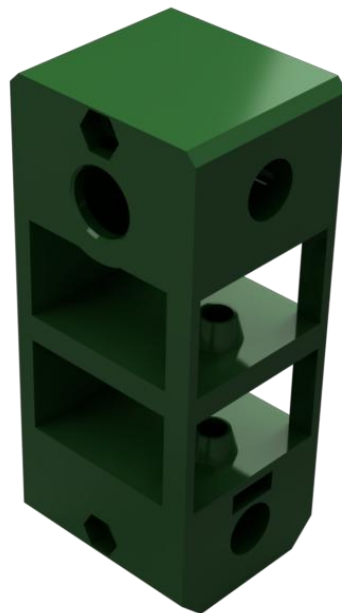


Fig. 58 shows the new model of the motion gantry.

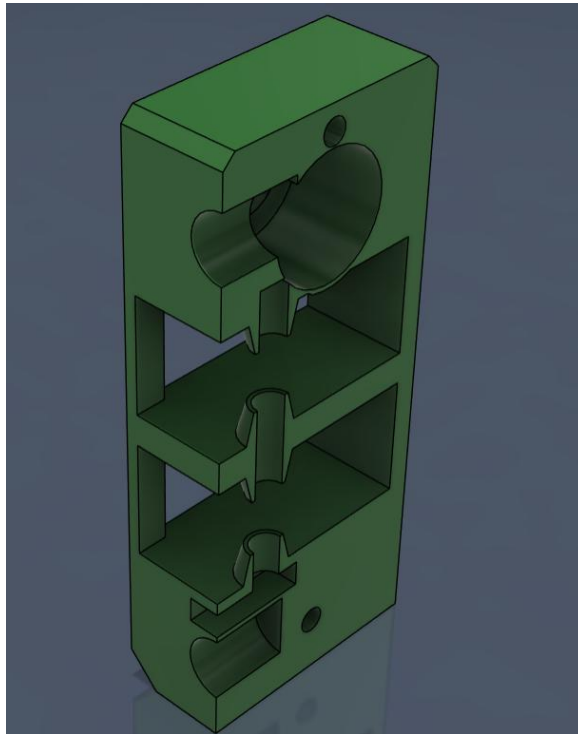


Fig. 59 shows one half of the part.

The part was designed in a way that allowed it to open, so that we can slide the bearing in and then enclose it from both ends. This allowed me to hold the bearing in an enclosure and avoid motion loss. The central screw was just placed inside without a nut, as it acted like a shaft and got enclosed inside as soon as the sides came together. This allowed me to design one part that isn't heavy and allows us to add everything inside. I also added a cut to add the nut inside the part, which allowed for an easier assembly of the part.

You can observe the dimensions of the gantry and the section dimensions below in Figure 60. This part also solved another problem that was related to the rigidity of the parts, as the part got wider, the distance between it increased, causing high flex between the sides, making a higher possibility of failure in the part.

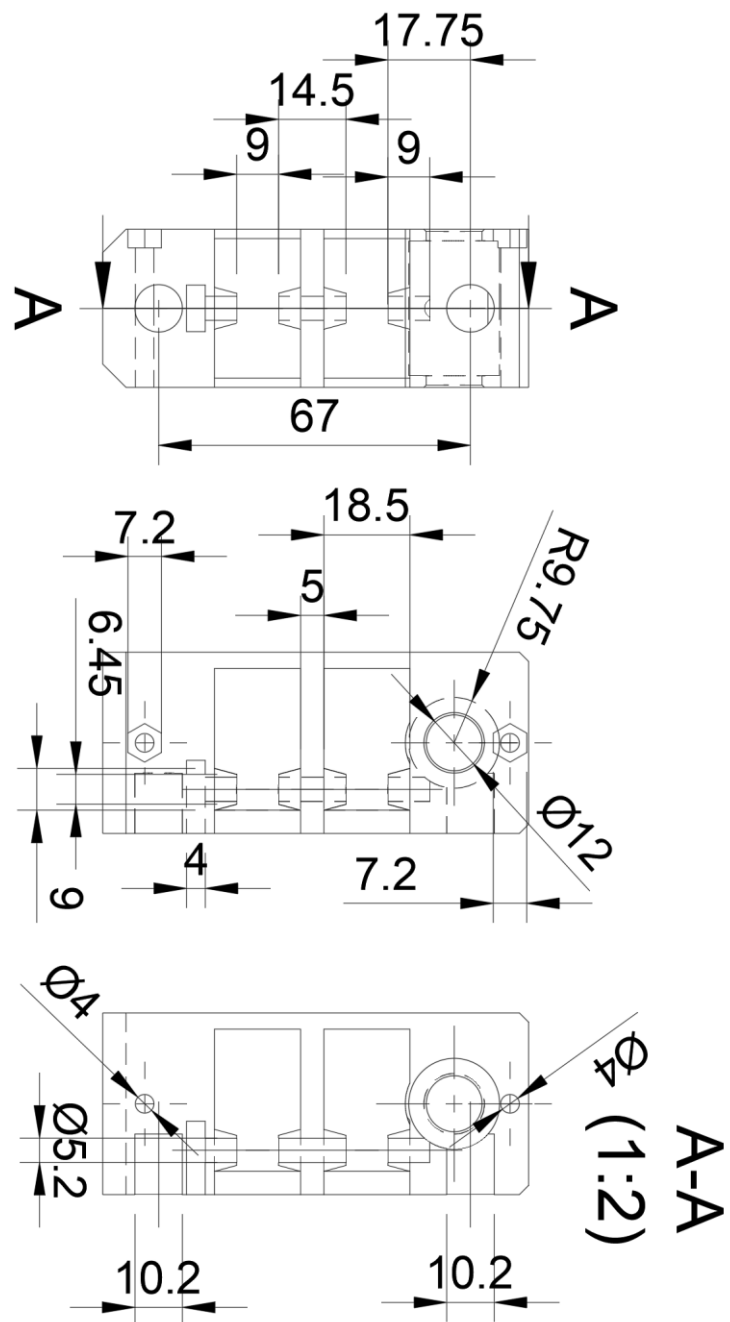


Fig. 60 shows the dimensions and the section dimensions of the gantry.

### 3.4.5 Base Mounts

#### 3.4.5.1 *First Design and why it was changed*

The base mounts were initially designed in a way that the base was supported from one side by a motor, and the other side was raised up with it. The base motor mounts were made as L-shaped motor mounts that were supposed to slide in, and you can check the motor mounts and the initial designs of the base mounts below in figures 61, 62, and 63. You can see the base was designed in a way that there were two motors connected to a linear threaded rod that were raising the machine, and the smooth rods were supporting the motion from the opposite end.

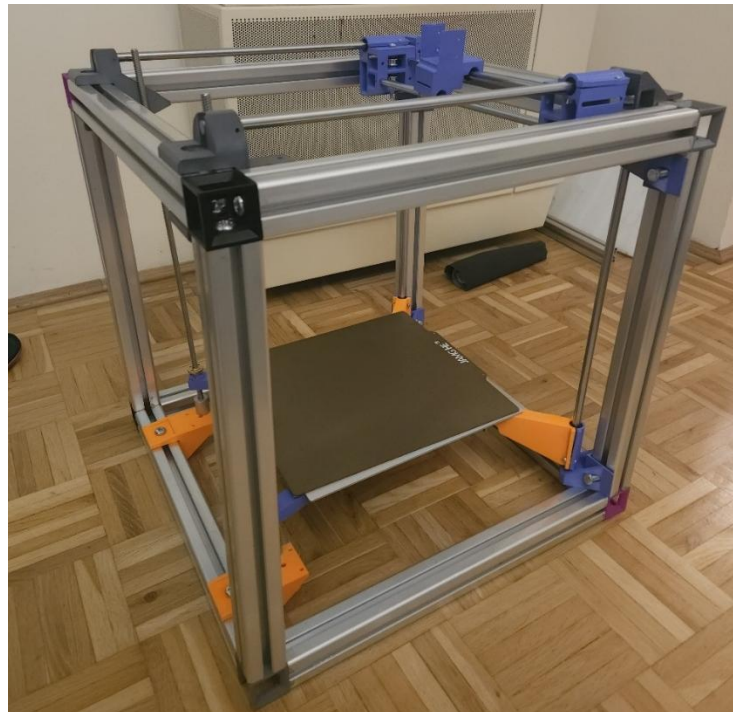


Fig. 61 shows the printer with the base mounts installed.

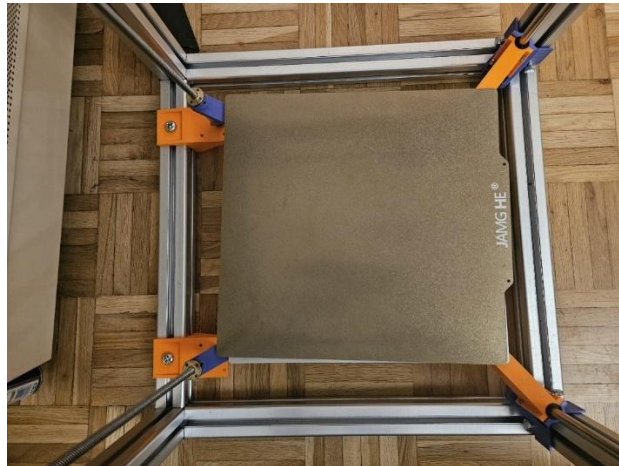


Fig. 62 shows the base mounts installed from the top view.

The base mounts had several problems as they were directly connected with the bed; they couldn't be made from PLA. ABS, or ASA, high-temperature materials were supposed to be used for it at least. The second problem was related to the bed bending from the front. If the bed moves in such a way that we cannot level the bed, the prints will always be unlevel and made with bad quality.

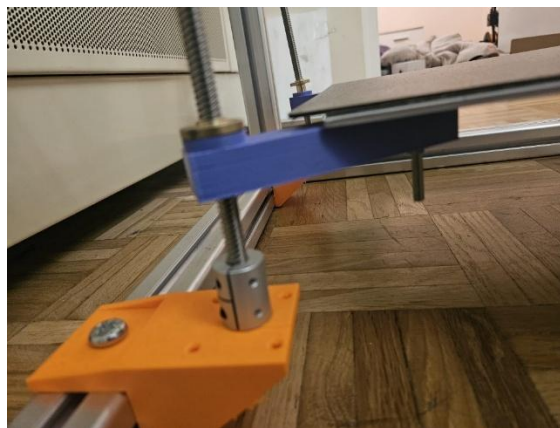


Fig. 63 shows the base motor mount and the motion arm.

Due to this, I had to select better motor mount designs, as we see in Figure 63, the motor mount I designed already shows cracks, and the motor wasn't even moving. The motor mounts were planned to be placed at all 4 corners, as it is a heavy bed, and NEMA17 48[mm] stepper motors could handle the combined force of the stepper motors. Later, due to material sourcing time, I managed to change the design to a 3-point motor design where all 3 motors move together to move the bed in the direction that we want.

#### 3.4.5.2 *Base motor Mounts*

The base mount was designed in the same way as the main motor mount for the X and the Y axes. The base motor mount was made in a way that it could clamp into the system, and the layout of the motors was planned and set accordingly. The base motors were placed in an orientation where there were two motors towards the back and a single motor in the front that supported the heated bed. The base motor mount had similar stiffening arms added to it. The base motor mount was moved up to the base so we can raise the motor a bit. There were slots added to the mounts clamp so we can tighten it easily. The dimensions can be seen in Figure 65. The base motor mount, similar to the top motor mount, has chamfered points at the start so we can easily add it to the aluminum extrusions.

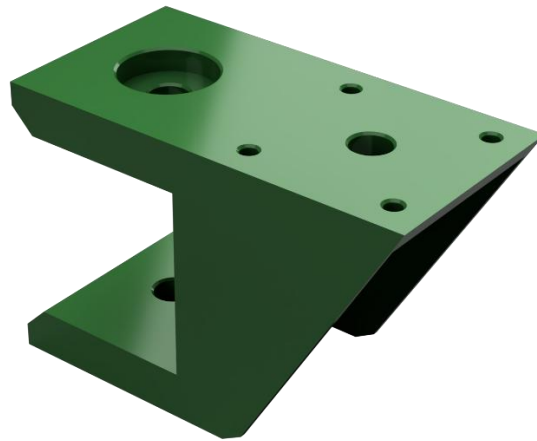


Fig. 64 shows the base motor mounts.

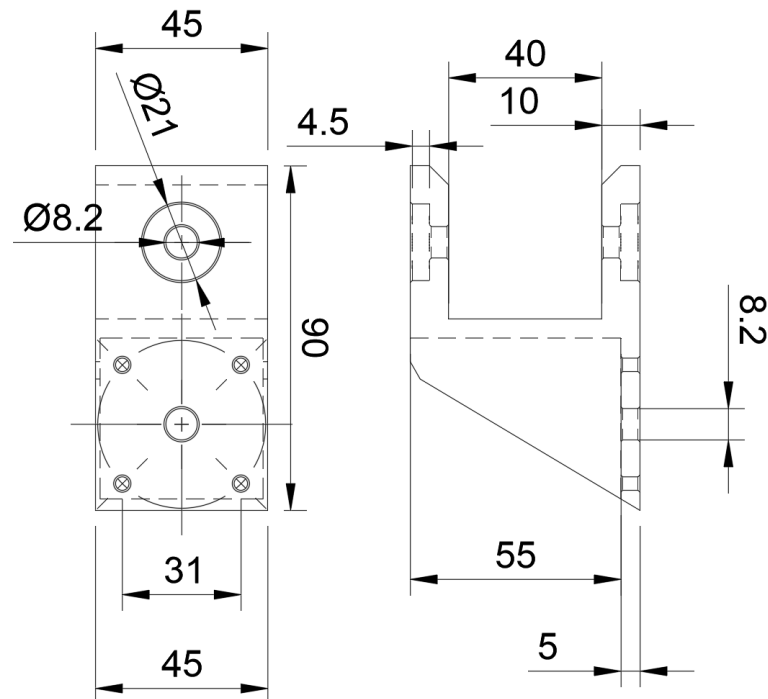


Fig. 65 shows the dimensions of the base motor mounts.

These motor mounts were aligned with the holes at two edges, and at the other side, one motor mount was placed in the centre of the frame that connected both sides of the holes. You can observe this triangular style placement in figures 66 and 67. These can be fitted in, and after observing the correct distance from the side, they were screwed in where the slot nut holder is placed in the bottom to aid in tightening it.

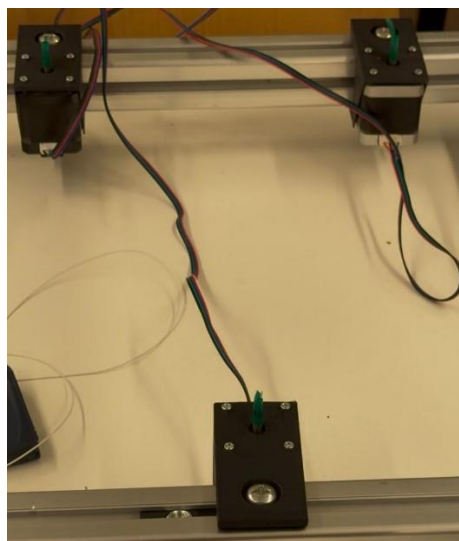


Fig.66 shows the motor mounts clamped into the base.

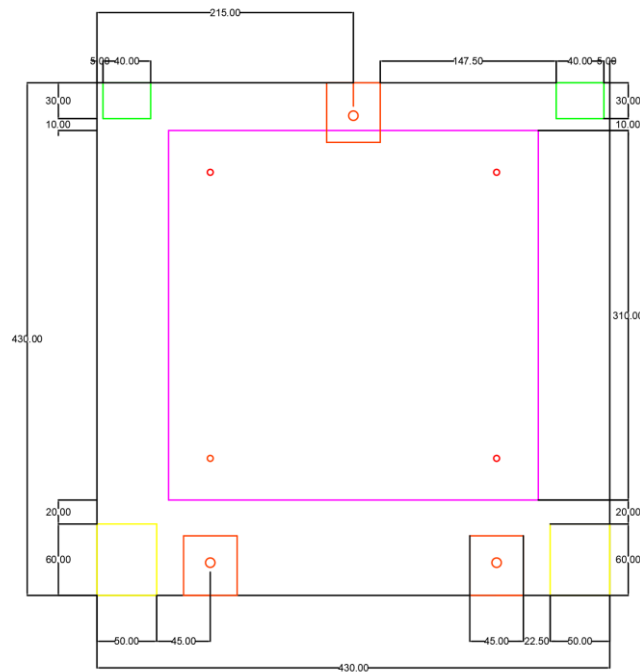


Fig. 67 shows the layout design of the base motor mounts.

The base motor mount layout was designed, and they were placed according to Fig. 67, where the pink part that can be seen is the Hot bed of the printer, sized at 310 X 310 [mm]. The red parts that are seen are the motor mounts that are placed for the base, and their dimensions can be seen. The yellow rectangles represent the motor mounts, and the green ones represent the bearing mounts. This layout can be seen applied in Figure 66.

#### 3.4.5.3 *Base mount left side design*

The base mounts, as seen before, refer to the sides of the printer from the access point of one of the sides, which required a modular design, while the other had two individual motors, so the design was kept plain and simple. The left side has two motors, and the bed is placed a bit closer to the motors than the right side, so the mounts are going to be linear mounts that connect the no-backlash nut directly to the hot bed. To make sure of this, there was a circular placement for the no backlash nut where it could be placed and screwed in; on the other side, indents were made for the nut to fit in so that it is easier to tighten it. The part can be seen in Figure 68, and the dimensions can be seen in Figure 69.



Fig. 68 shows the motor to bed connector.

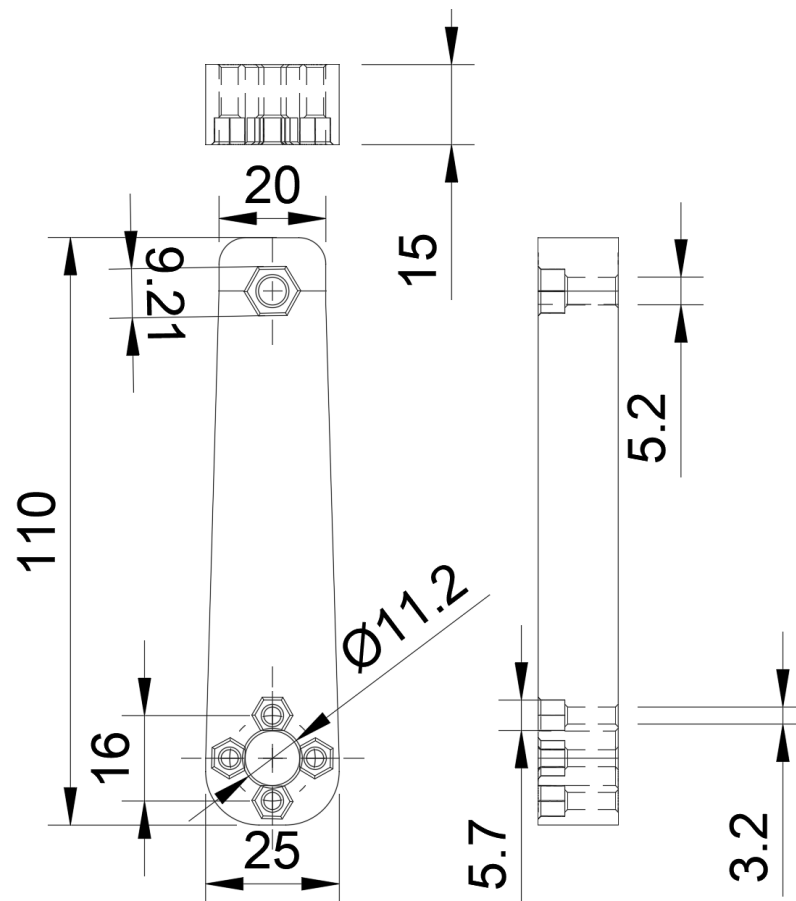


Fig.69 shows the dimensions of the motor arms.

#### 3.4.5.4 Base mount right side design

The right side mount was more complex, and since we want to make it in a way that the least possible changes should be made to increase the size of the machine,

the part was made as a 2-part assembly where two parts were made, one was made to remain constant, and if any change was required, it was supposed to be made to the smaller modules. Changing the length of the left side arms and modules will allow this design to remain modular. This can be seen in the design of the modules, which have a hexagonal aligner that helps them to align with the part properly. The parts after they are fitted in are screwed in, and there is a hexagonal indent on the opposite side that allows us to put the nut in and tighten it easily. The overall design was made so that the part is modular, simple, and easy to increase in size. The part can be seen in Figure 70, and the design and dimensions can be observed in Figures 71 and 72.

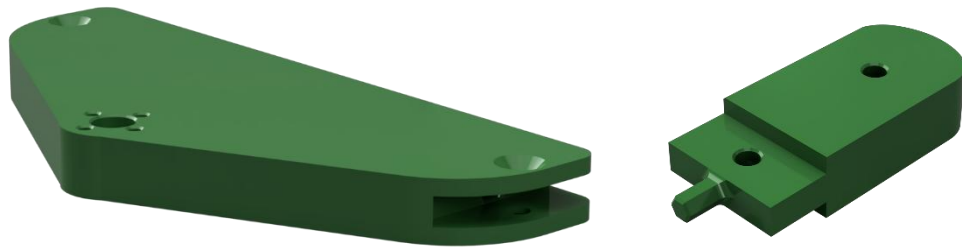


Fig. 70 shows the parts for the base mount.

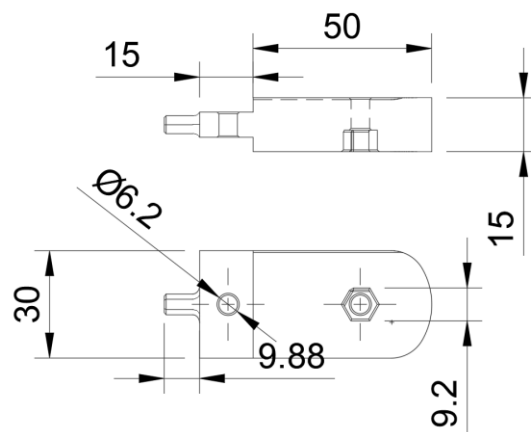


Fig. 71 shows the dimensions of the base modular connector.

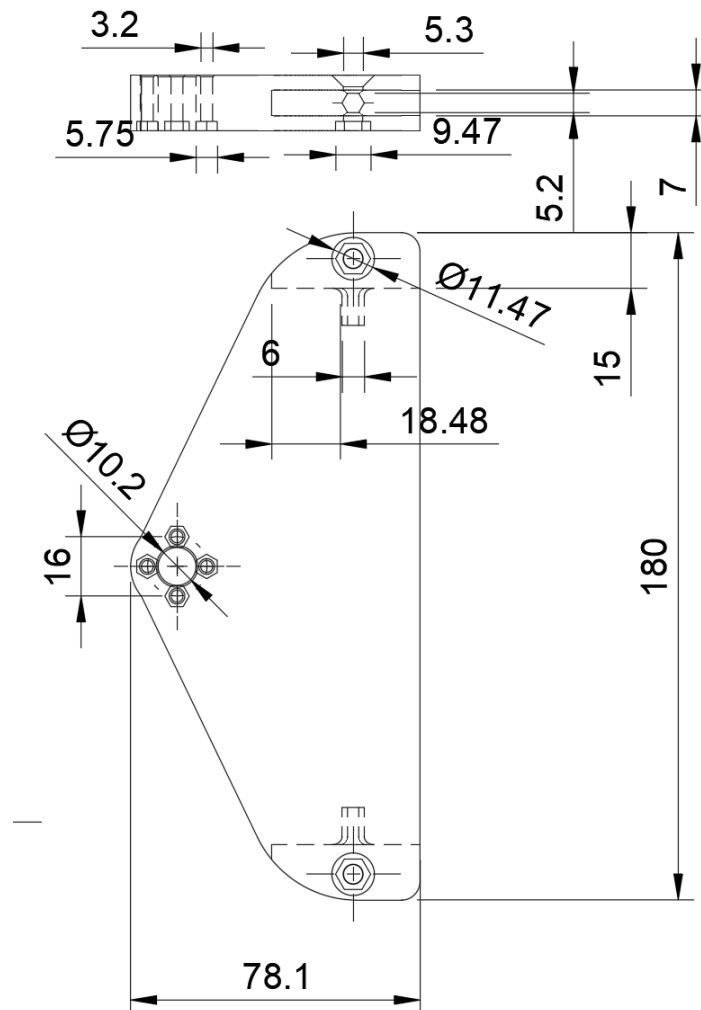


Fig. 72 shows the base connector mount from the base to both side connectors and the non-backlash nut.

The modular connector fits into the mount. The connection tolerance can be seen below in Figure 73. The base holes align, and then the screws are tightened. This design allows us to connect the singular motor to both sides and make the design extendible by changing the modules connected to the end.

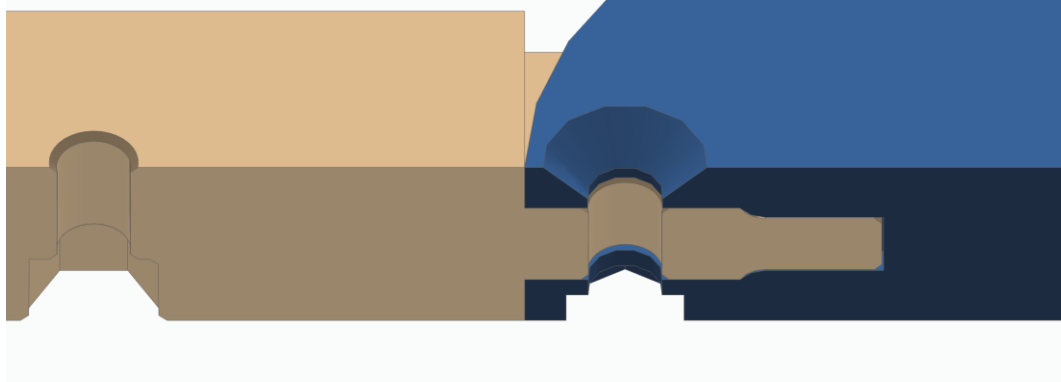


Fig. 73 shows the connection between the parts in the left base connector.

#### 3.4.5.5 *Base Raisers/Printer Feet*

After making the base parts, I designed parts to raise the 3D printer like its feet. These parts were placed at all 4 corners of the machine. The printer feet were made in a conical shape, where the top was made 0.5 [mm] shorter than the width of the aluminum extrusions, and the height was selected as 40 [mm]. The part can be seen in Figure 74, and the dimensions of the figure can be seen in Figure 75. The screw was tightened from below to fit it inside the nut slot holder and to make sure that the part fits perfectly to the base of the frame.



Fig.74 shows the base feet mount part.

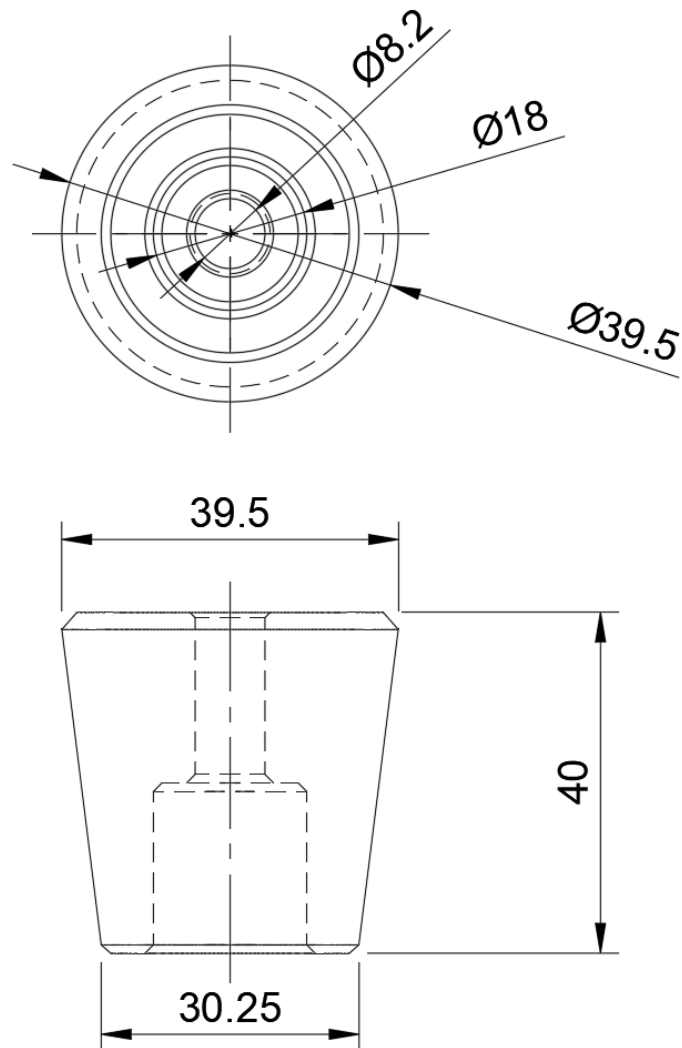


Fig.75 shows the base raiser of the 3d printer.

### 3.4.6 Slot Nut holder

The slot nut holder is a casing that slides into the slots of the extrusion bars and can hold the nut. This allows the nut to be tightened, and you don't need to hold it from the outside. The T slot nut holder is simply a case/cover for the nut that makes it easier to tighten the screw inside and makes sure that the parts fit perfectly. The Nut holder is used with every part that has a connection with the base frame of the machine, such as the feet, all the motor mounts, and the bearing holders. I made it fit the nut perfectly and a bit longer so that if it moves, it rests against the walls and allows the screw to tighten. The nut holder is able to enter due to its shape, which

can be seen in Figure 76. The dimensions of the nut holder can be seen in Figure 77.

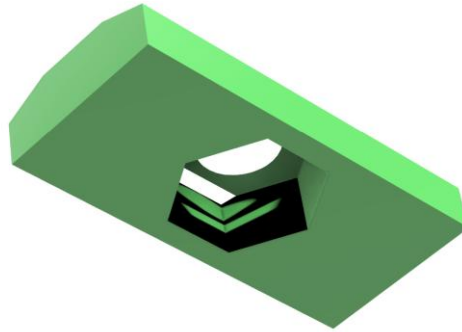


Fig. 76 shows the nut slot holder.

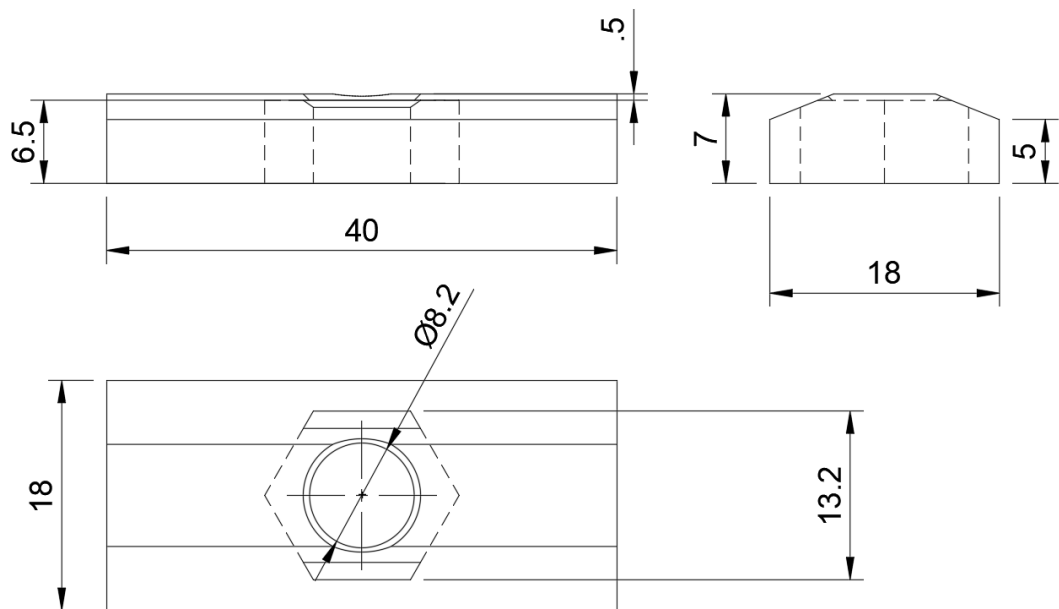


Fig.77 shows the dimensions of the nut slot holder.

### 3.4.7 Extruder Mount

The extruder mount is a casing that has 3 purposes. It allows the belts to connect to the extruder as the belts connect to the extruder mount, not the extruder itself. It holds the extruder, and it acts as a casing for the two linear bearings as they are required to provide motion to the system. The part splits into two, and the bearing is placed inside it, and it is tightened. The extruder mount has independent holders that allow it to mount the parts, such as the extruder cover and the part cooling fan, too. You can see the part and its one section in figures 78 and 79. The dimensions of the part can be observed in Figure 80.

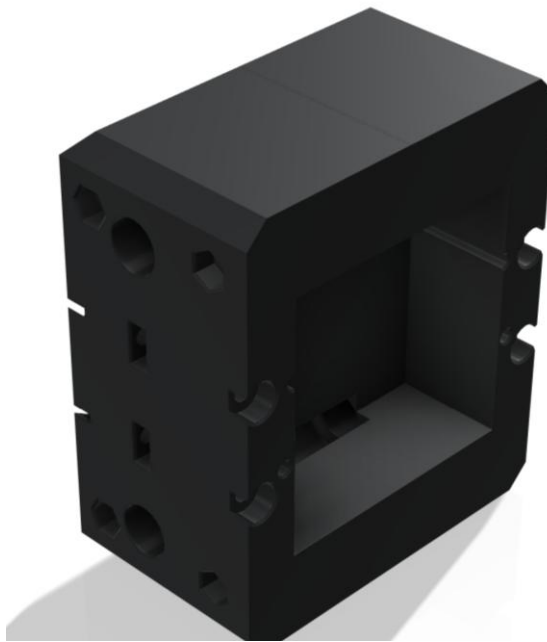


Fig. 78 shows the extruder mount.

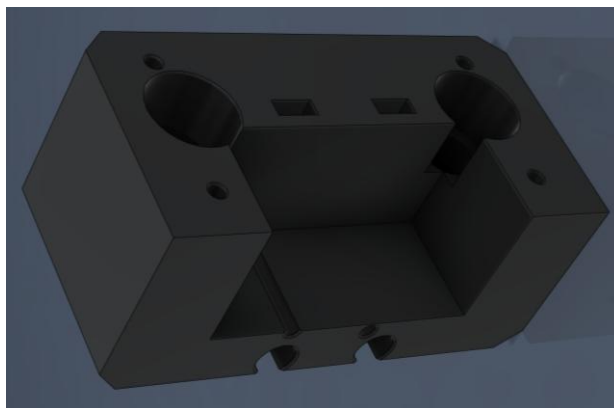


Fig.79 shows one side of the extruder mount.

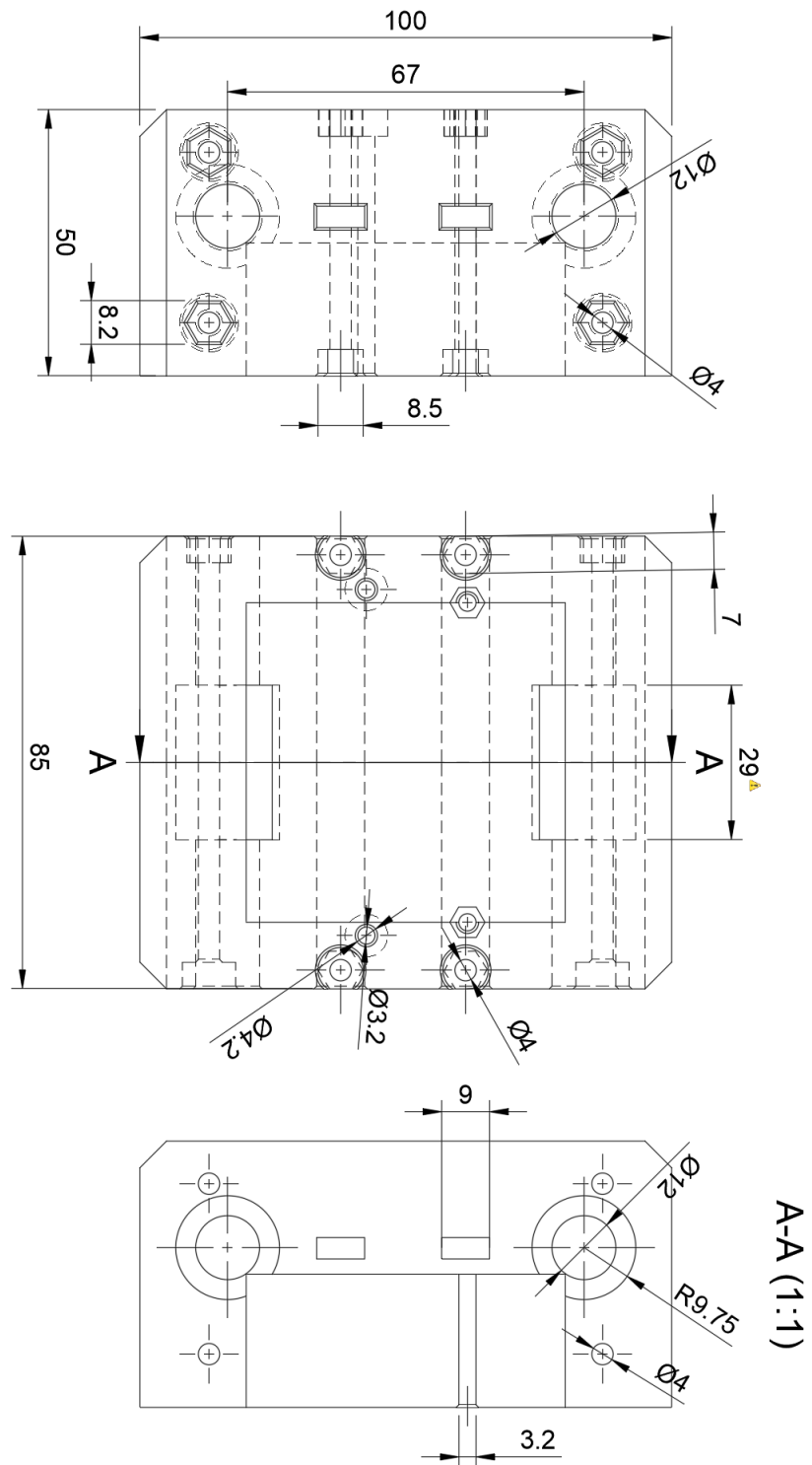


Fig.80 shows the dimensions of the extruder mount.

### 3.5 Extruder and Hot Bed

The extruder consists of a few parts: the extruder motor, the cold end, the PTFE tube inside, the part cooling fan, the nozzle, the cold end fan, and the heater and thermistor. These parts can be seen below in Figure 81. The red casing that can be seen is the Part cooling fan duct. The motor can be seen in two parts: the motor and the extruder gears. The conductive probe sensor can be seen, which allows for bed leveling, and the hot and cold ends can be seen.

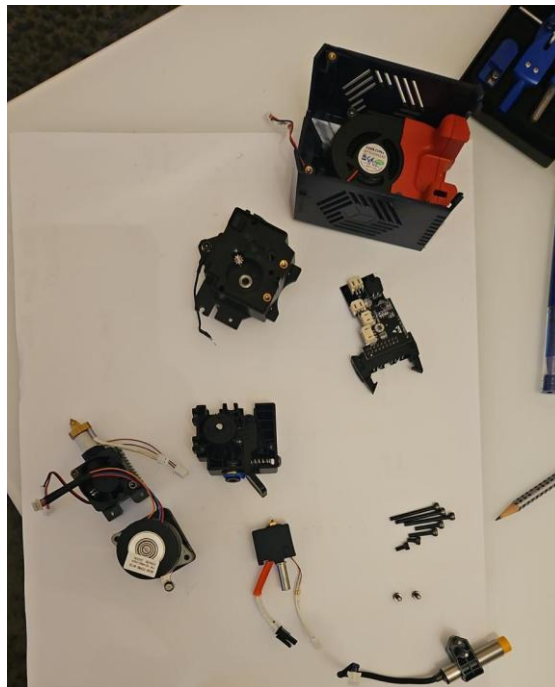


Fig.81 shows the parts for the extruder.

The Extruder was fixed, and the mount was made according to the extruder. The base mount hot end was fitted into the cold end of the assembly. The cold end was then inserted with a PTFE tube that gives the filament a passage from the extruder to the hot end. A thermal paste was applied to the heat break, and it was fitted inside the cold-end heat sink of the assembly. The PTFE tube was added to the heatsink, and it was fitted to the extrusion motor mechanism. The assembly can be seen below in Figure 82.



Fig. 82 shows the extruder assembly.

After this assembly was created, it was fixed to the mount. This allows me to fit the outer casing and install the part cooling fan and the casing of the machine, as seen in Figure 83. Before installing the probe, a sensor was added to the side of the cold end to assist in bed detection and leveling. This can now be installed into the machine, and then the machine is ready for complete assembly.

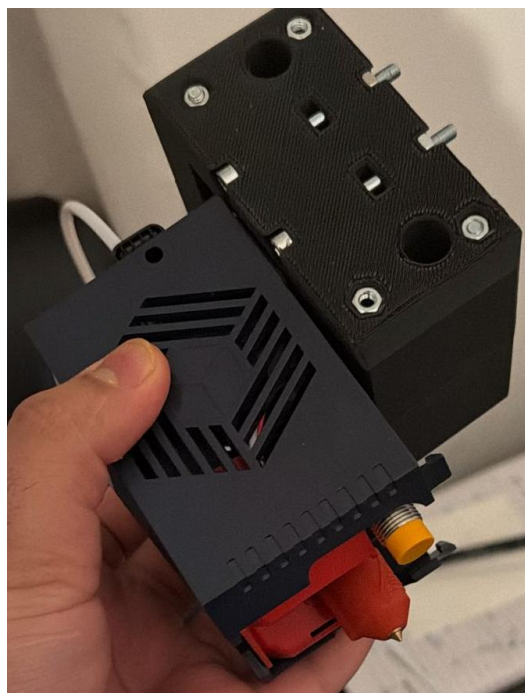


Fig.83 shows the completed extruder assembly.

The heated bed of the machine was installed with a 100 Kohm thermistor to detect the temperature at the point marked NTC. I connected the head of the thermistor there and then added high-temperature adhesive glue tape there. After installing this, the front of the bed had a magnetic plate that was stuck using high-temperature adhesive. This allowed us to install the magnetic build plate on which

the part will be printed. An excess of the magnetic sheet was cut using a cutter. The textured PEI plate was placed on top of it for the prints.

### 3.6 One-Hand Assembly System and Assembly

After the parts were made, they were 3D printed with PLA plastic to check the fitting. The base parts were later made with ABS plastic. The PLA showed the parts were fitting accurately, the tolerances were good, and the screws were fitting perfectly. After this, the belt was installed, as can be seen in Figure 84. After fitting the two mounts, the smooth rod was passed through the motor mount to the bearing mount. The motors were installed, and the bearings were fitted. The central gantry was assembled, and then it was placed inside with the bearings and the extruder mount. After this was done, I had to test the motion of the X and the Y axis. The belt was installed in the system, and it was checked for tension. After which, the Heated bed was placed, and it was mounted in place.

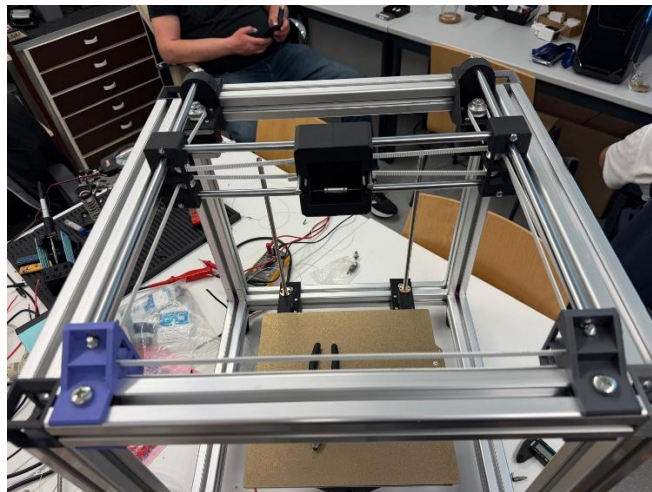


Fig. 84 shows the assembled machine with belts installed.

The one-hand assembly system that I thought of was used to make all the parts for this assembly. The one-hand assembly system stated that any part that I was making was made considering 6 things in mind, such as:

- Any part that is designed needs to be printable and optimized for 3D printing,
- Any designed part should be made considering the assembly process,
- The least possible motion should be used for the assembly,
- The parts that are being made should be modular least possible parts should be changed to increase or decrease the machine size,

- The parts should be made in a way that every part that is 3D printable can be made in less than a day.
- The parts that are designed should allow for fewer assembly motions, considering dual functionality (if possible).

Considering all of the rules I made for myself of the one-hand assembly system. This has made the machine so easy to assemble that I have disassembled and reassembled the entire machine into parts more times than I can count.

## 3.7 Electronics

### 3.7.1 Motherboard and Wire Length Adjustment

The BTT octopus motherboard was used for my project. Before using the board, I had to make some changes. First thing was removing the jumpers from the board for a few areas and preparing the board. The first was preparing the board for UART mode, as I was going for a TM2209 stepper driver. So, for this, you need to just keep the second jumper and remove the rest of the jumpers. After this, the second was the fan jumpers. Based on the voltage, the jumpers were removed and adjusted, as I am using all the fans that have 24 volts, so I removed all the jumpers and kept them at the bottom one. After this, the MCU jumper was removed so that the board could power only from the power supply, and the stall guard jumpers were added, enabling sensorless homing. [53]

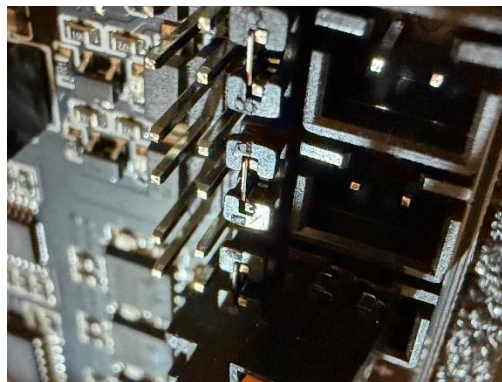


Fig.85 shows the jumpers.

After this, the stepper drivers were added, and the power supply was connected to the motherboard as per the instructions. The switch and the plug were soldered to the input of the power supply, and the outputs were connected to the sections of the board for bed, motors, and motherboard power. [53]

After this, the soldering was done to increase the wire lengths. We marked the lengths of the wires and increased them to reach the motherboard. The wires were marked and soldered, and at both ends, connectors were installed on the wires. The connectors were then joined to the motherboard, connecting all the wires for the extruder, including the probe sensor. The reference was taken from the image I have attached below. The board was then connected, and the extruder and all the motors were checked, but the stepper motors weren't working.

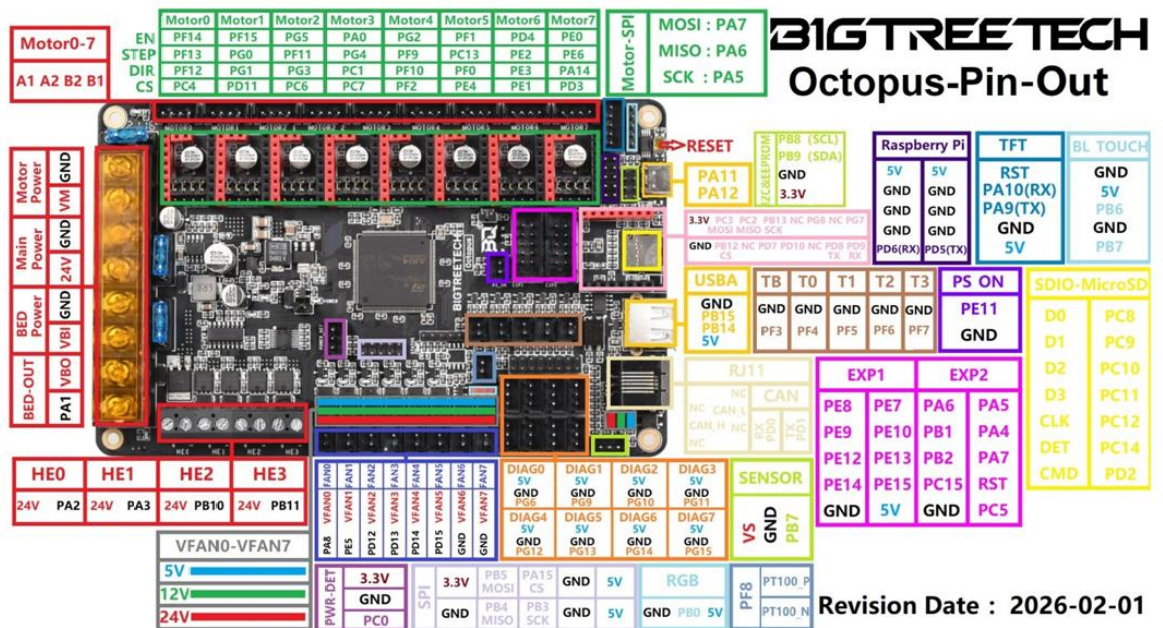


Fig.86 shows the pinout of the motherboard. [53]

### 3.7.2 Stepper motor Problem

After the connection was made successfully, the stepper motor was checked, and they were not working. This was then checked as we needed to see the input and the output coils of the stepper motors and the motherboard. After analysing all of them, I saw that the stepper motors and the wires had different inputs and outputs compared to the motherboard. After this, we removed the wires from the pins and checked them again, and they were working perfectly. After this, the second batch of motors had the same problem. As I ordered motors from different suppliers, I got 2 motors with different outputs. Using the ammeter, I checked the stepper motors and then fixed the wires, and after this, the installation was correct. Tape was placed

on the motor to perform tests for everything and check it using Pronterface. The G28 was used to move all motors and check them, and they were working after this.

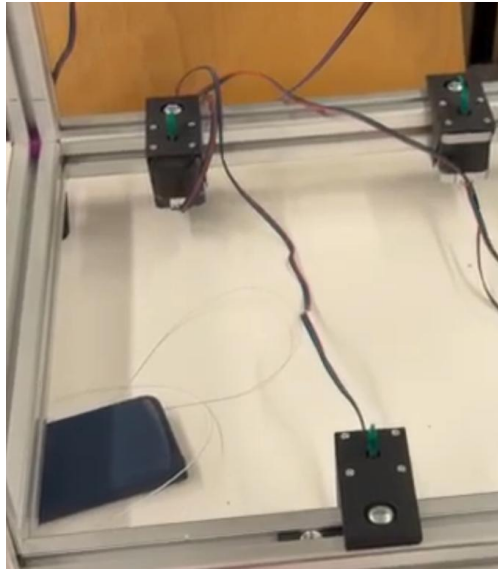


Fig.87 shows the test of the motors.

### 3.8 Software setup

After this, I used Claude AI to program the 3D printer. This was done with me giving a prompt and explaining the setup of the software, as I wanted to use Klipper firmware, but instead of using a Raspberry Pi, I wanted to use my laptop as the connection point to the Klipper. I added this and then gave it information related to the printer. After giving the complete information, the AI guided me through installing Linux inside Windows. After installing Linux, we went to Moonraker software through Linux, and in Moonraker, I created the firmware.bin file. The firmware details can be seen, which show more details I added and can be seen in the appendix section, figures 93 to 96. This shows the calculated steps and the pinouts.

### 3.9 Finalizing and Testing

After finalizing the software, I added it to the machine and then started it, which helped me install the firmware into the machine. After this, I performed several tests. Firstly, I checked if all the sensors were working perfectly, as can be seen in Figure 88. The other sensors, including the sensorless homing, were tested.

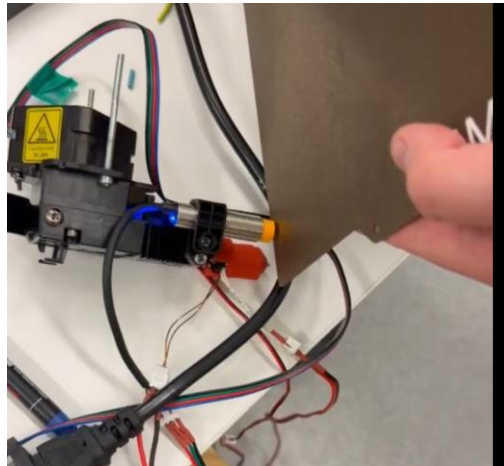


Fig.88 shows the inductive sensor working.

After testing this, the motors were tested, and the direction of one of the motors was reversed, so I went to the firmware and changed it to make sure all the motors rotate in the same direction for the bed. After this, I moved the bed upwards till the sensors and the motors work together to sense it and send a signal to the motherboard to stop it, which worked perfectly, as can be seen in the figure. 89 The bed is completely up and printed.

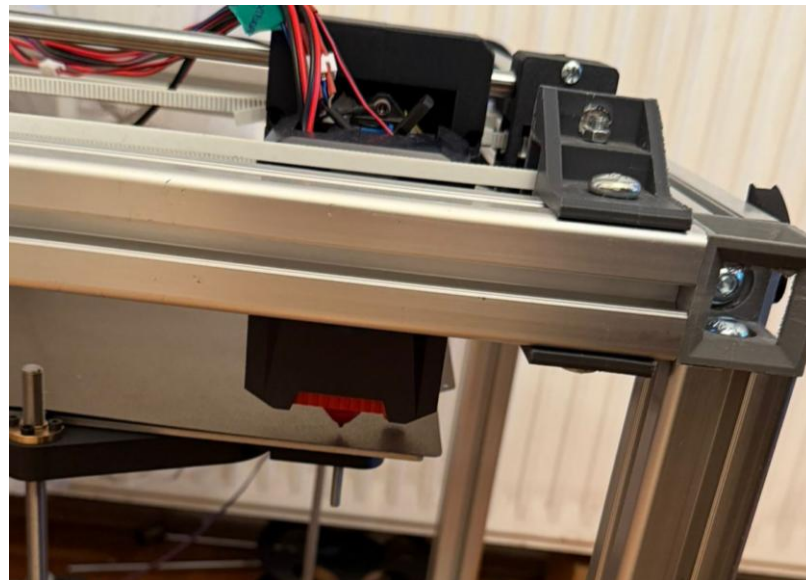


Fig 89 shows the extruder sensing the bed.

After checking this, the last test was to check the extruder if it extrudes the filament correctly. For this, I removed the top PTFE tube and then inserted a small amount of filament. After this, I pressed the extrude button of the device, and it

started to extrude the filament. The Temperature of the nozzle also increased very quickly.



Fig. 90 shows the filament leaving the nozzle

### 3.10 Summary and future possibilities

The machine is ready, all the materials and software are working accurately, which shows success, and since the parts are all usable in various areas, the machine is made with a sustainable mindset. The machine, as can be seen in Figure 91, is working, with all the temperatures checked. Although future plans include giving it a pair of smooth rods so it can move up and down smoothly, and giving it an enclosure with a high-temperature engineering filament for parts. Although with the help of my supervisor, I was successful in completing this machine as a part of my thesis.

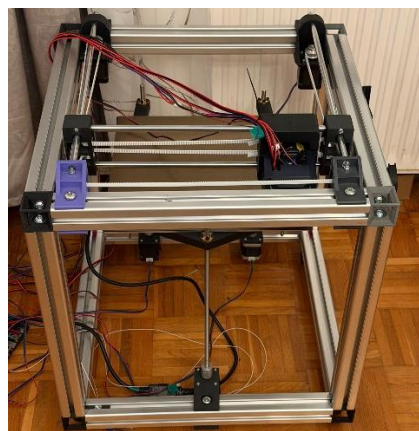


Fig. 91 shows the final machine.

With my future studies, I want to implement a rig-rig system with this machine that can help automate the system of 3D printing more machines like this one, turning it into an automated system where one machine will be able to use the same parts and produce machines bigger, its own size, and smaller than the machine we can see.

## 4 Appendix

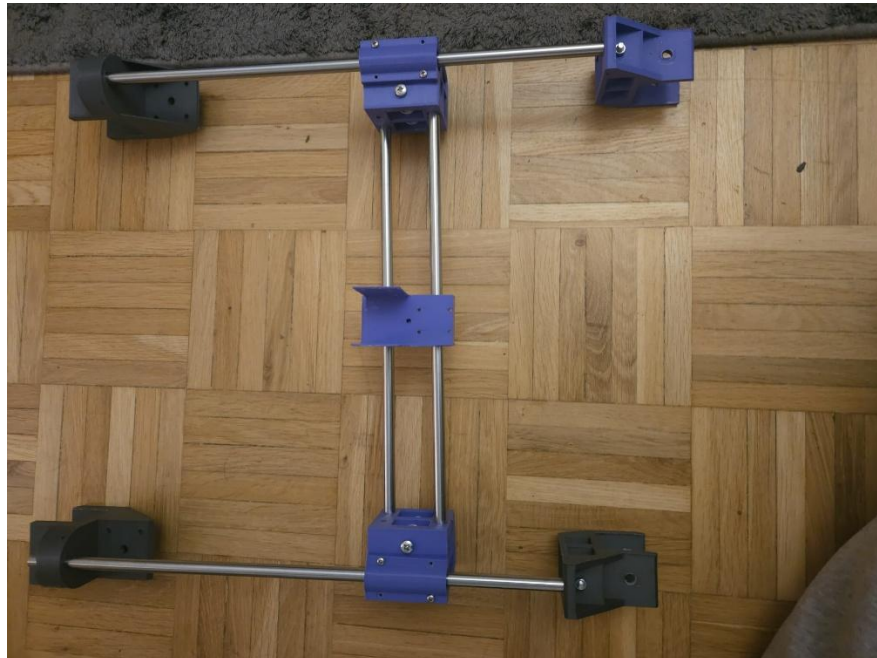


Fig. 92 shows the Core X-Y mechanism with a false extruder.

```
# =====
# printer.cfg - Custom CoreXY 200mm
# MCU:      Octopus Pro STM32F446
# Kinematics: CoreXY
# Extruder: Anycubic Kobra 2 Pro extruder
# Hotend:   Creality K1 Max (ATC Semitec 104NT-4-R025H42G)
# Probe:    Inductive (Anycubic Kobra 2 Pro)
# Z:        Triple Z with z_tilt (Front-left, Front-right, Back-center)
# =====

[include mainsail.cfg]

# -----
# Mainsail / Moonraker extras
# -----

[exclude_object]

[respond]
default_type: echo

# -----
# MCU
# -----

[mcu]
serial: /dev/serial/by-id/usb-Klipper_stm32f446xx_3E00460005513434373238-if00

# -----
# Printer limits
# -----

[printer]
kinematics: corexy
max_velocity: 300
max_accel: 3000
max_z_velocity: 10
max_z_accel: 100
square_corner_velocity: 5.0

# -----
# X Stepper (sensorless homing - SpreadCycle required)
# -----

[stepper_x]
step_pin: PF13
dir_pin: PF12
enable_pin: !PF14
microsteps: 16
rotation_distance: 40
homing_speed: 40
homing_retract_dist: 0
endstop_pin: tmc2209_stepper_x:virtual_endstop
position_endstop: 0
position_max: 200
position_min: 0

[tmc2209 stepper_x]
uart_pin: PC4
run_current: 0.800
stealthchop_threshold: 0
driver_SGTHRS: 80
diag_pin: PG6

# -----
# Y Stepper (sensorless homing - SpreadCycle required)
# -----
```

Fig.93 shows the firmware.

```
# -----  
[stepper_y]  
step_pin: PG0  
dir_pin: PG1  
enable_pin: !PF15  
microsteps: 16  
rotation_distance: 40  
homing_speed: 40  
homing_retract_dist: 0  
endstop_pin: tmc2209_stepper_y:virtual_endstop  
position_endstop: 0  
position_max: 200  
position_min: 0  
  
[tmc2209 stepper_y]  
uart_pin: PD11  
run_current: 0.800  
stealthchop_threshold: 0  
driver_SGTHRS: 80  
diag_pin: PG9  
  
# -----  
# Z Steppers - Triple Z  
# -----  
[stepper_z]  
step_pin: PF11  
dir_pin: PG3  
enable_pin: !PG5  
microsteps: 16  
rotation_distance: 8  
endstop_pin: probe:z_virtual_endstop  
position_max: 250  
position_min: -3  
  
[tmc2209 stepper_z]  
uart_pin: PC6  
run_current: 0.800  
stealthchop_threshold: 999999  
  
[stepper_z1]  
step_pin: PG4  
dir_pin: PC1  
enable_pin: !PA0  
microsteps: 16  
rotation_distance: 8  
  
[tmc2209 stepper_z1]  
uart_pin: PC7  
run_current: 0.800  
stealthchop_threshold: 999999  
  
[stepper_z2]  
step_pin: PF9  
dir_pin: PF10  
enable_pin: !PG2  
microsteps: 16  
rotation_distance: 8  
  
[tmc2209 stepper_z2]  
uart_pin: PF2  
run_current: 0.800  
stealthchop_threshold: 999999  
  
# -----  
# Extruder  
# -----  
[extruder]
```

Fig.94 shows the firmware.

```
# Extruder
# -----
[extruder]
step_pin: PC13
dir_pin: PF0
enable_pin: !PF1
microsteps: 16
rotation_distance: 4.637
nozzle_diameter: 0.400
filament_diameter: 1.750
heater_pin: PA2
sensor_type: ATC Semitec 104NT-4-R025H42G
sensor_pin: PF4
min_temp: 0
max_temp: 300
min_extrude_temp: 170
control: pid
pid_Kp: 21.527
pid_Ki: 1.063
pid_Kd: 108.982
pressure_advance: 0.035
pressure_advance_smooth_time: 0.040

[tmc2209 extruder]
uart_pin: PE4
run_current: 0.600
stealthchop_threshold: 0

# -----
# Heated bed
# -----
[heater_bed]
heater_pin: PA1
sensor_type: EPCOS 100K B57560G104F
sensor_pin: PF3
min_temp: 0
max_temp: 130
control: pid
pid_Kp: 54.027
pid_Ki: 0.770
pid_Kd: 948.182

# -----
# Probe
# -----
[probe]
pin: PB7
x_offset: 0
y_offset: 0
z_offset: 0
speed: 5
lift_speed: 10
samples: 3
samples_result: median
sample_retract_dist: 2.0
samples_tolerance: 0.010
samples_tolerance_retries: 3

# -----
# Safe Z home
# -----
[safe_z_home]
home_xy_position: 100, 100
speed: 50
z_hop: 10
z_hop_speed: 10

# -----
```

Fig.95 shows the firmware.

```
# -----
# Z tilt
# -----
[z_tilt]
z_positions:
  0, 0
  200, 0
  100, 200
points:
  15, 15
  185, 15
  100, 185
speed: 150
horizontal_move_z: 8
retries: 5
retry_tolerance: 0.010

# -----
# Bed mesh
# -----
[bed_mesh]
speed: 150
horizontal_move_z: 5
mesh_min: 15, 15
mesh_max: 185, 185
probe_count: 5, 5
algorithm: bicubic
bicubic_tension: 0.2
fade_start: 1.0
fade_end: 10.0

# -----
# Fans
# -----
[fan]
pin: PA8

[heater_fan hotend_fan]
pin: PE5
heater: extruder
heater_temp: 50.0
fan_speed: 1.0

[controller_fan board_fan]
pin: PD12
idle_timeout: 30

# -----
# Virtual SD card
# -----
[virtual_sdcard]
path: /home/klipper/printer_data/gcodes
on_error_gcode: CANCEL_PRINT

# -----
# Macros (PRINT_START, PRINT_END, etc.)
# -----
[gcode_macro PRINT_START]
... (macro continues)

# =====
# SAVE_CONFIG block
# =====
### <----- SAVE_CONFIG ----->
### DO NOT EDIT THIS BLOCK OR BELOW. The contents are auto-generated.
```

Fig.96 shows the firmware

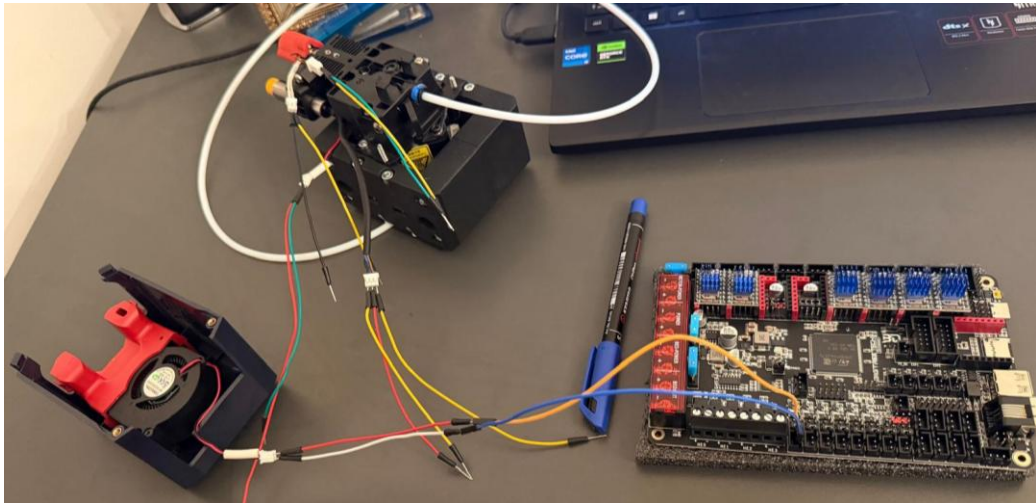


Fig. 97 shows the first few connections with the motherboard.

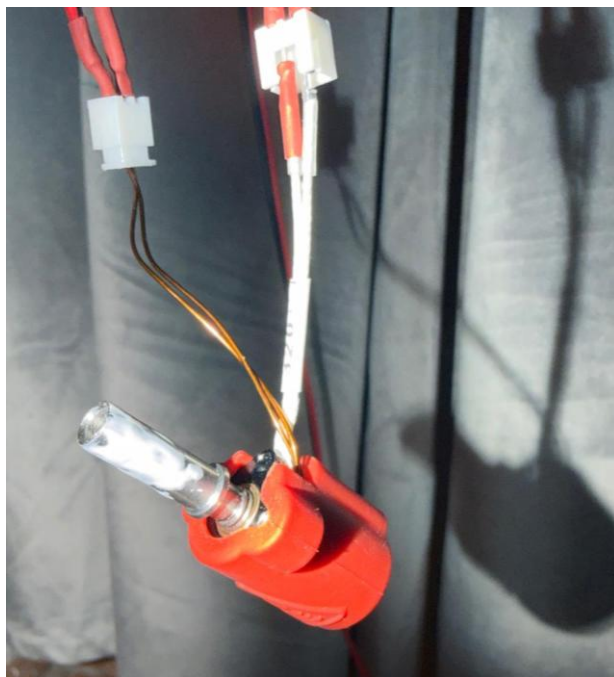


Fig.98 shows the thermal paste applied.



Fig.99 shows the first model from front.

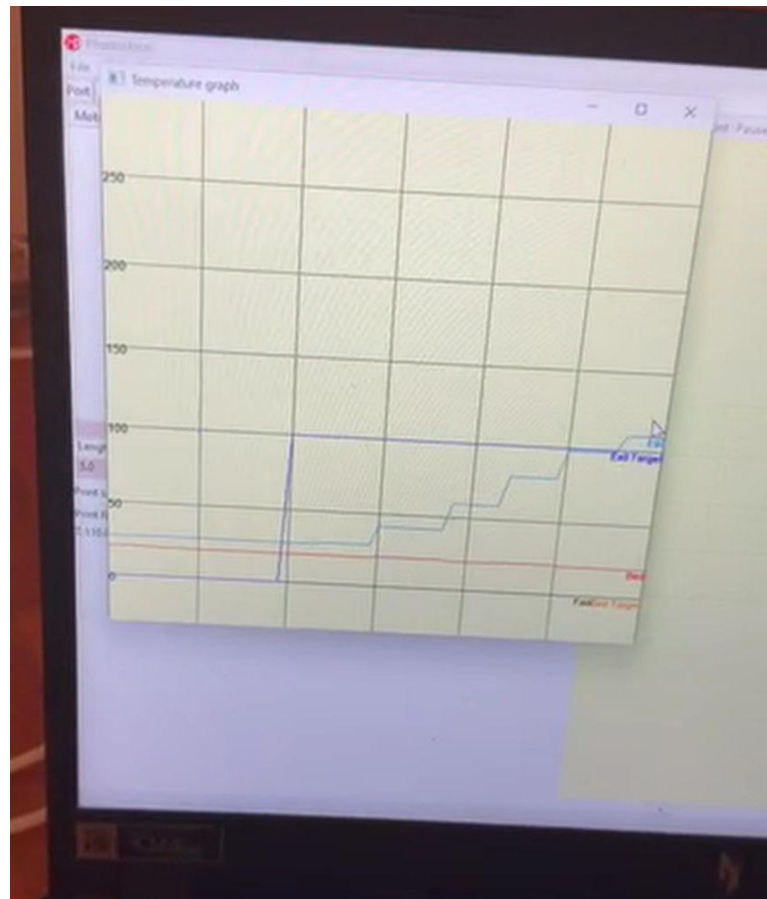


Fig.100 shows the nozzle temperature rising and all the other temperatures.

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